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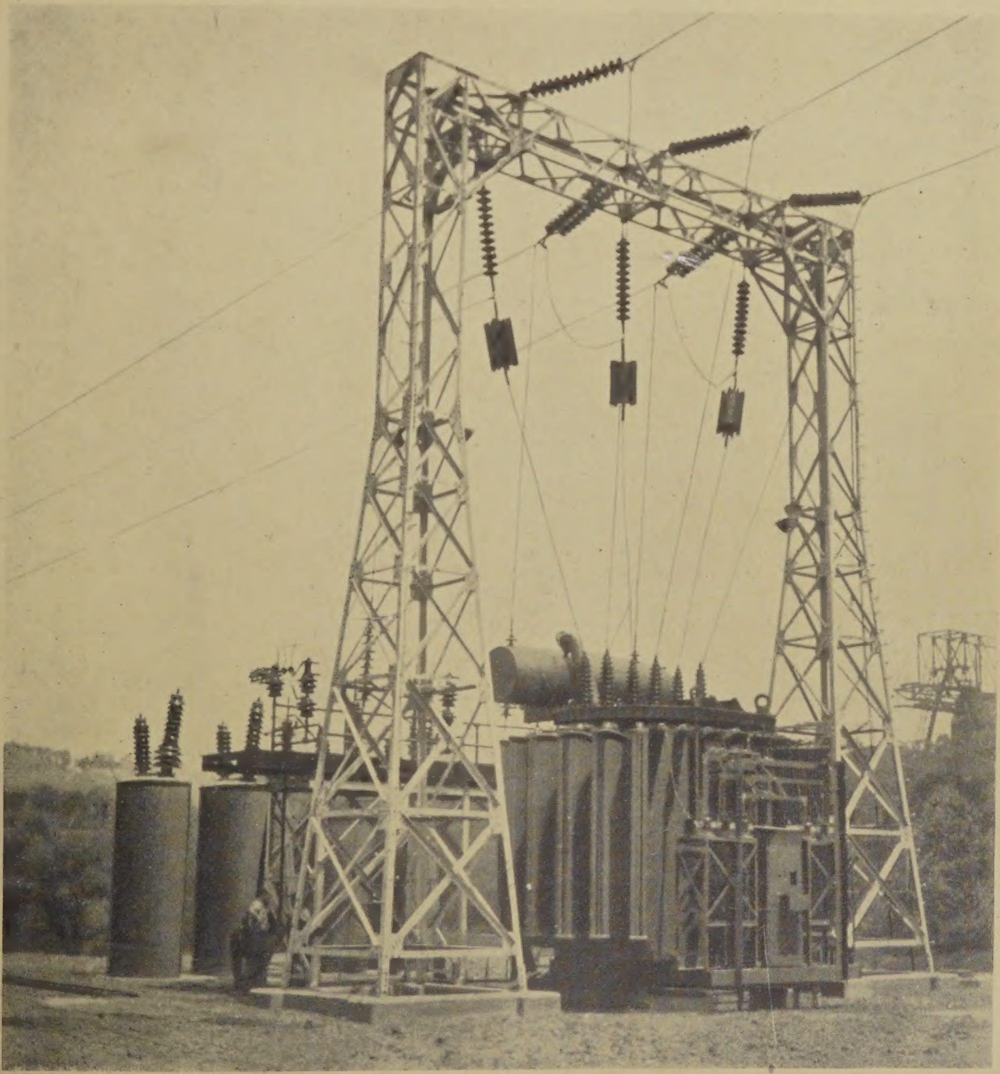
GENERAL ELECTRIC REVIEW

VOL. XXVIII, No. 12
DECEMBER, 1925



TYING AN ELECTRICAL KNOT

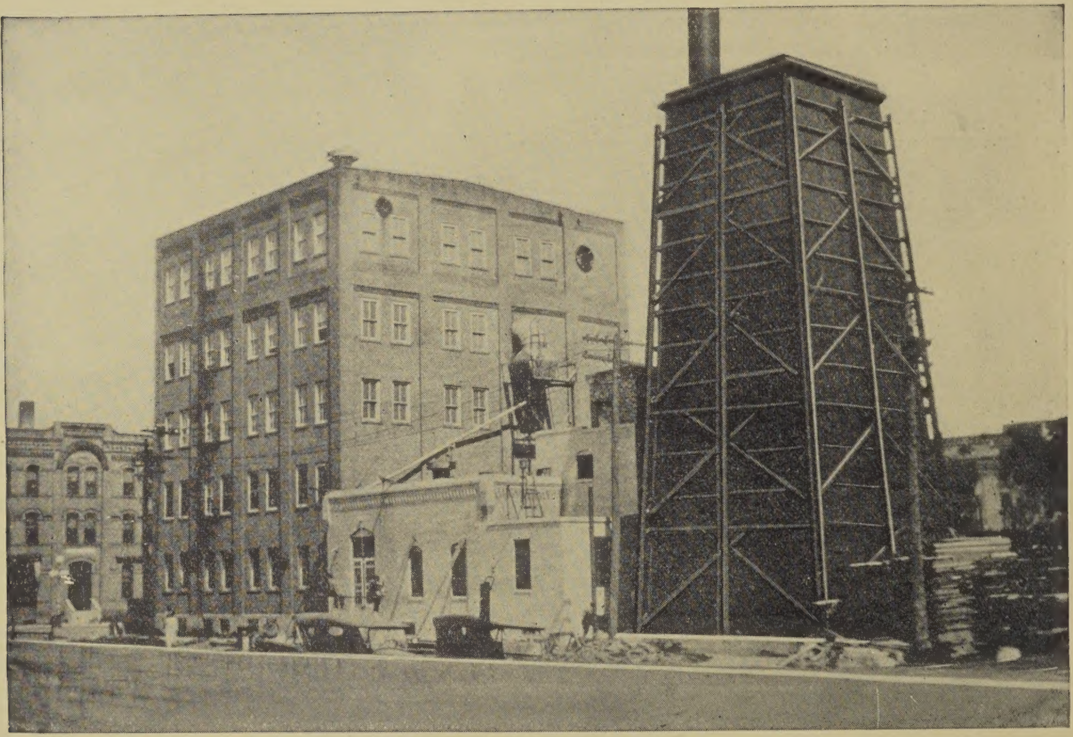
The large transformer shown here unites the power systems of the Duquesne Light and the West Penn Power Companies of Pennsylvania, and by means of its load ratio control mechanism will transfer power in either direction to secure a proper load balance between the two systems

(See p. 823)

In This Issue:

Marine Propellers
D-c. Reclosing
Lightning Arresters
Light Projection
Tie-in Transformers
Electrically Manufactured Ice
Electric Railway in Java
Charles A. Coffin Ry. Award
Arc Welding in Manufacture

WHEELER COOLING TOWERS



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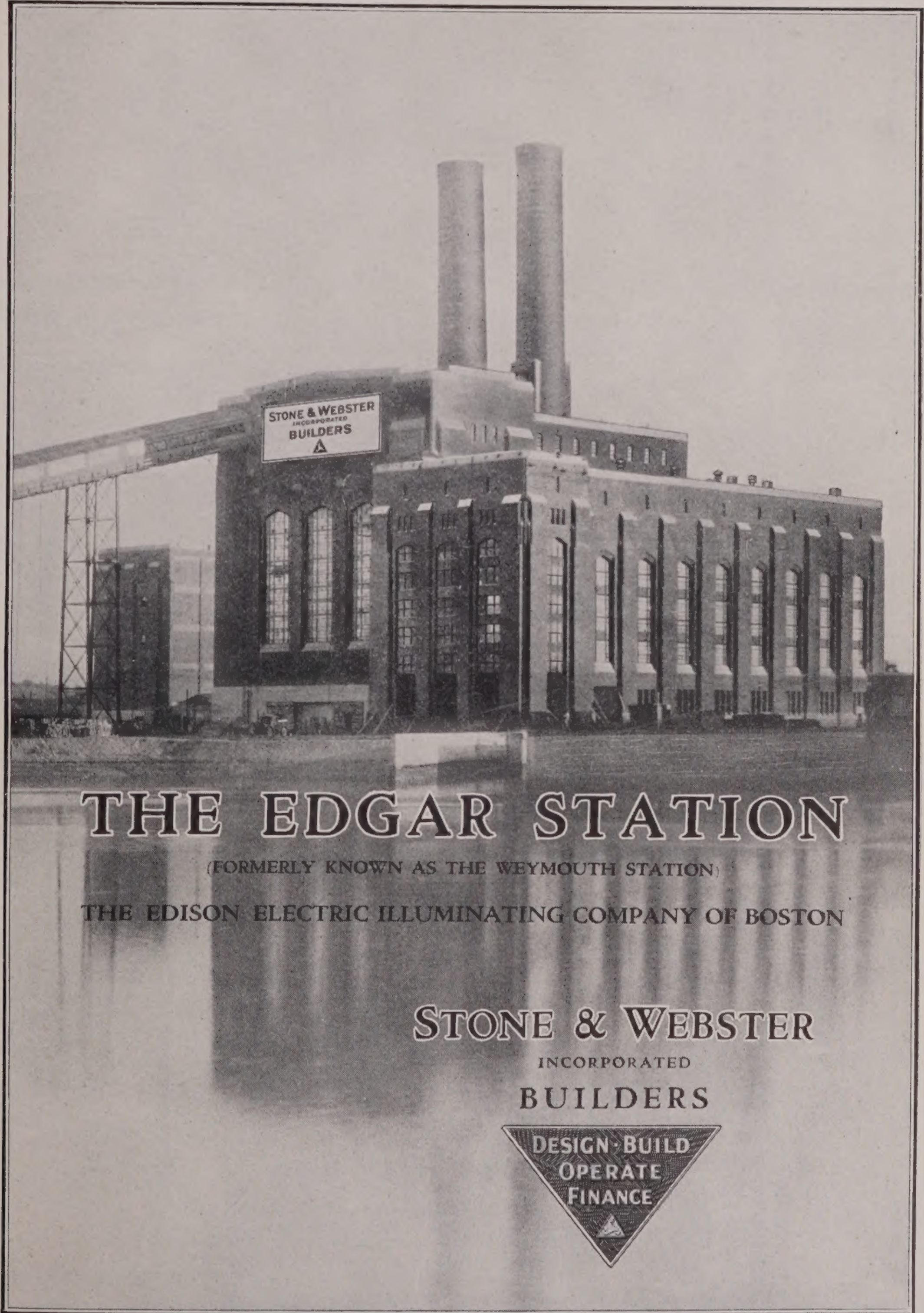

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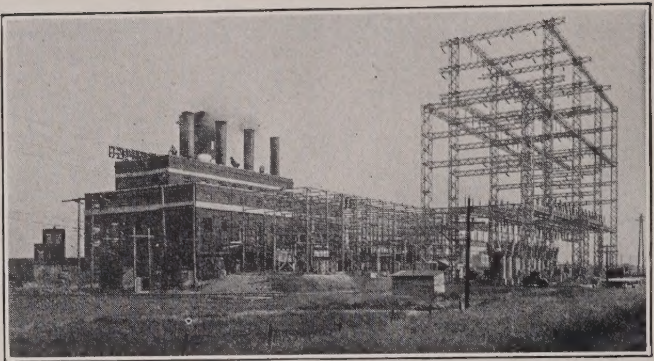

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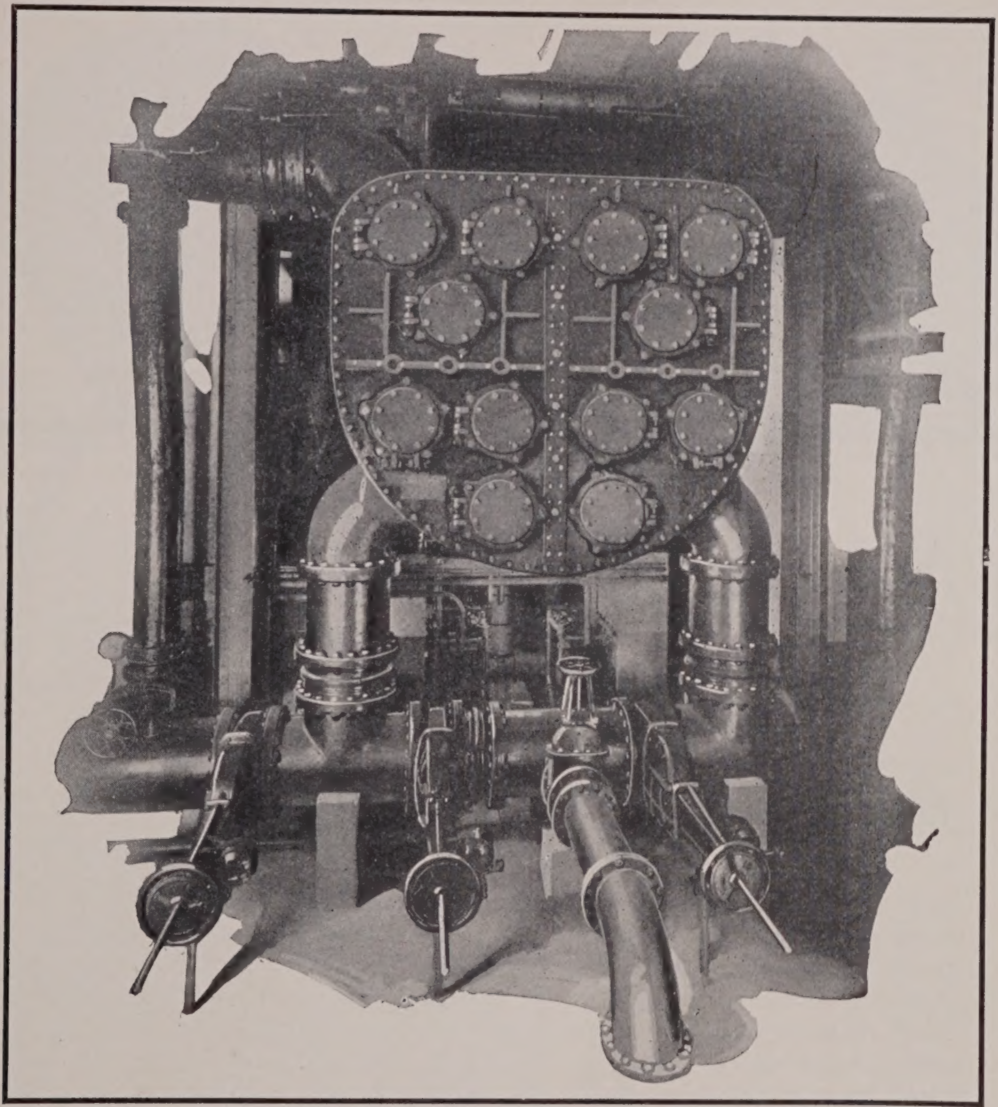

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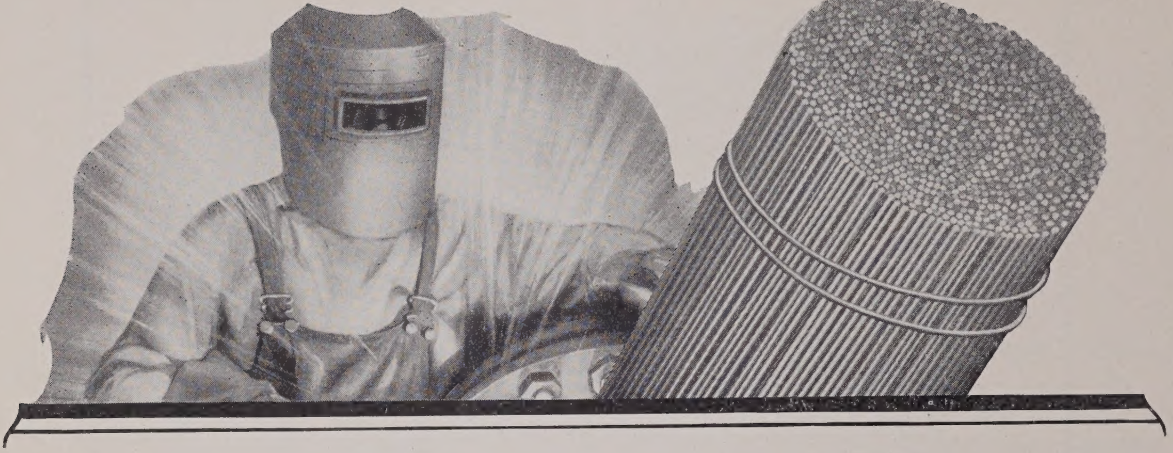

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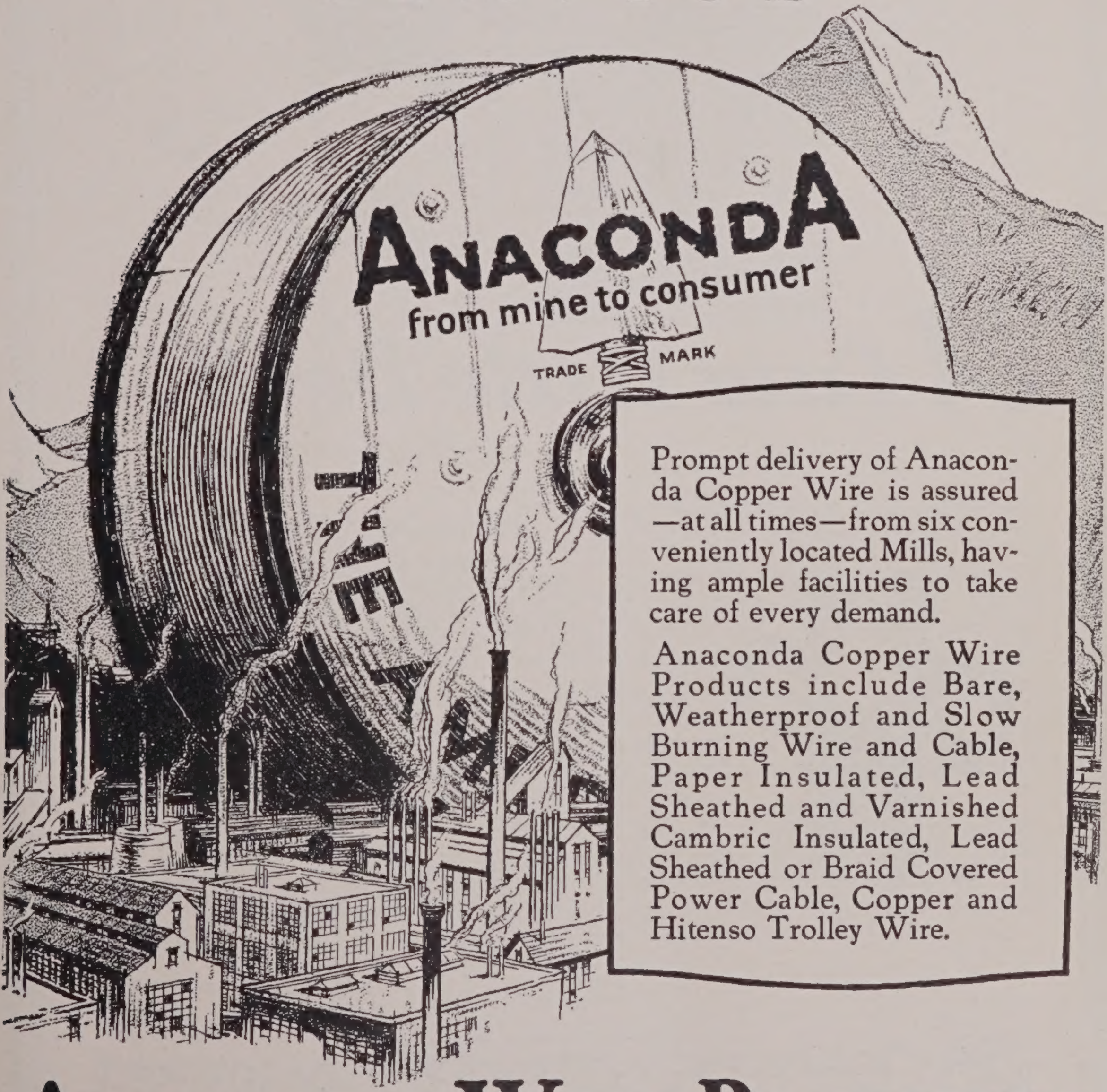

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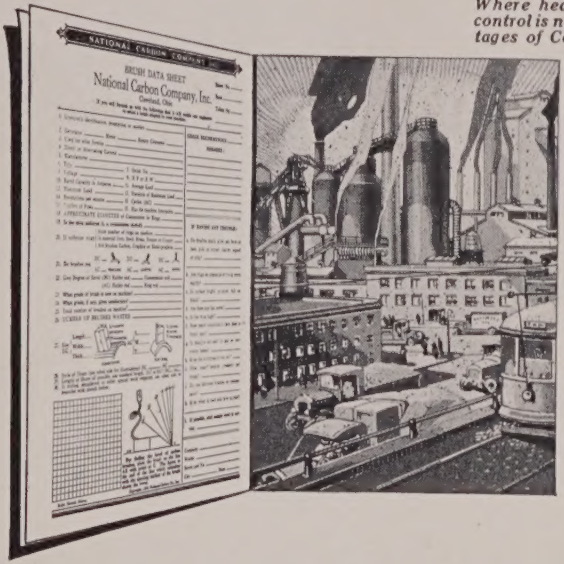

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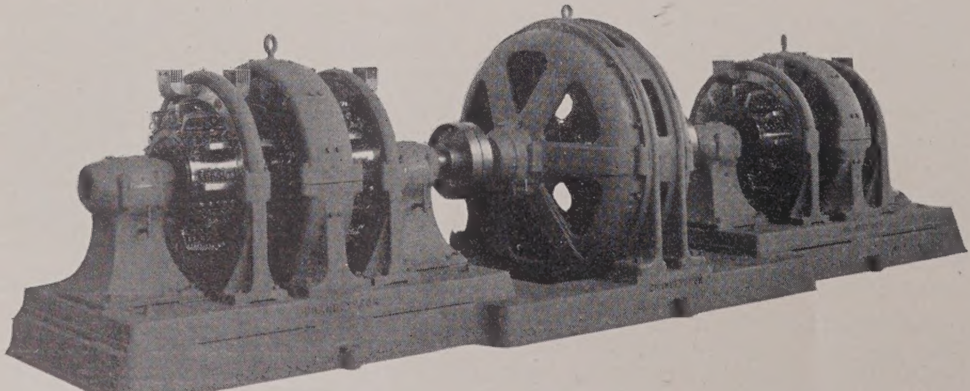

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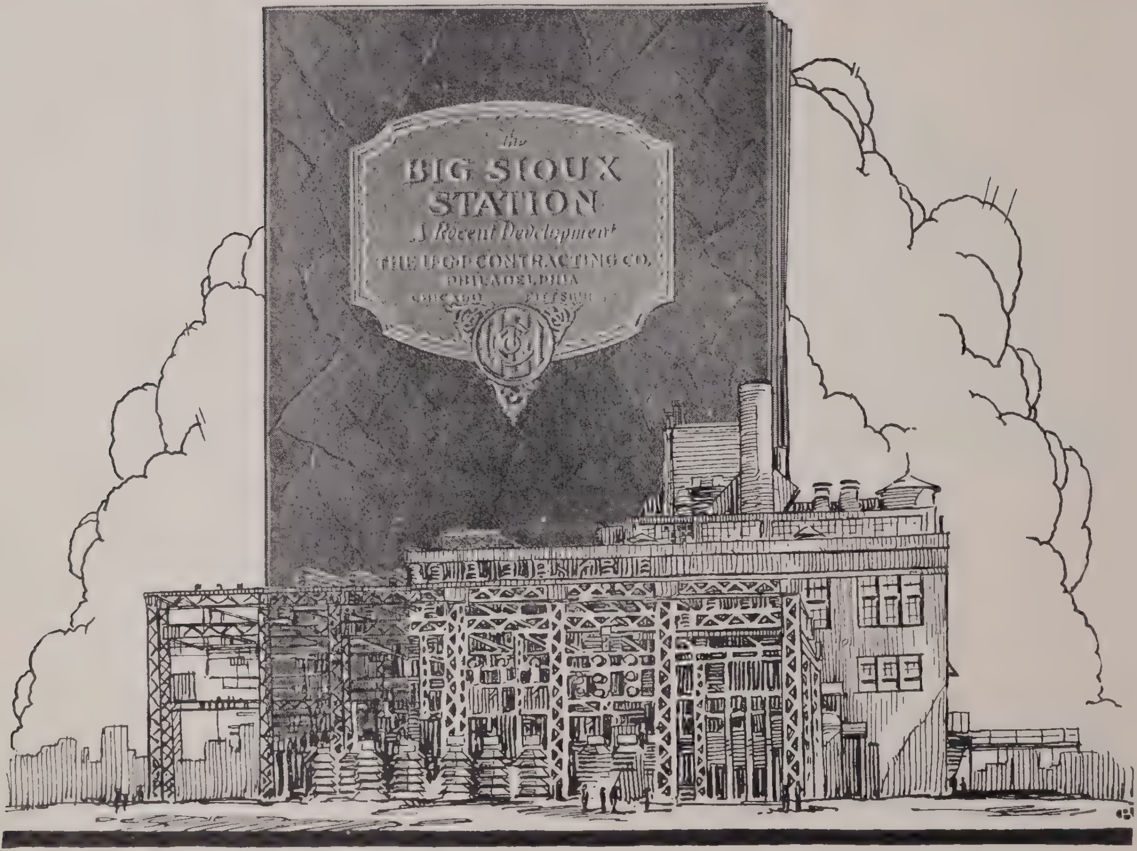

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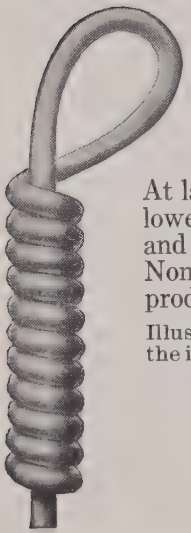

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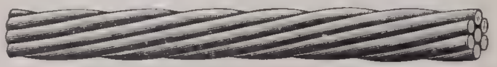

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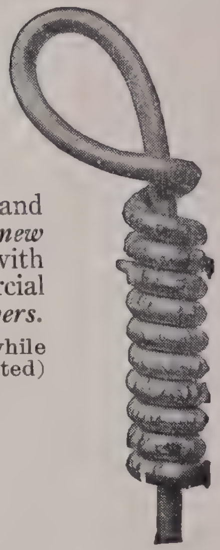

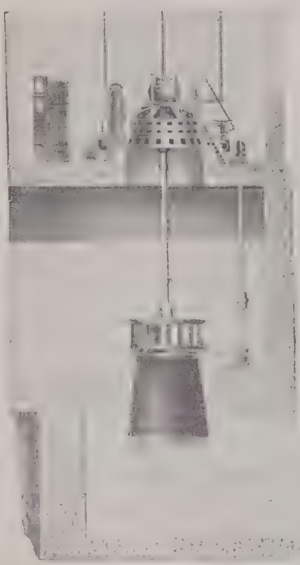

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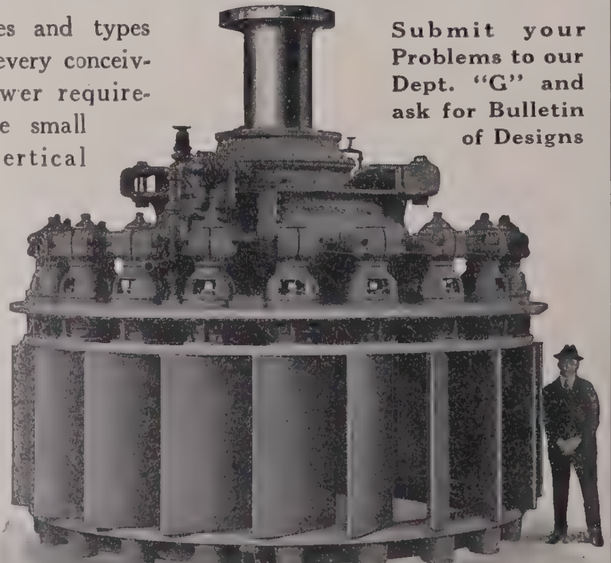
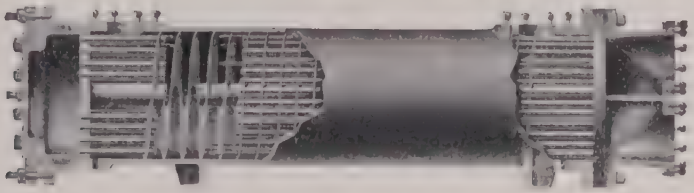


Prevents overheated turbine bearings



The G-R Multiwhirl Cooler keeps turbine bearing and reduction gear oil at the temperature for proper lubricating effect. A safeguard against overheated bearings and a help to greater oil economy. Over 2000 in use.

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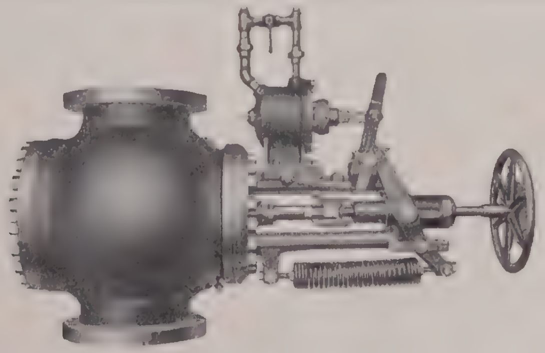

When a break occurs in the steam header
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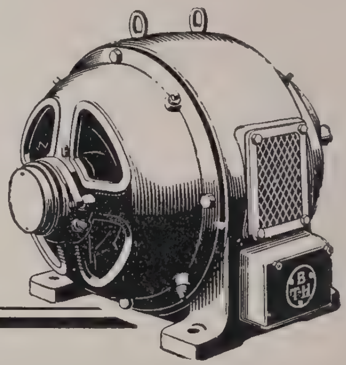

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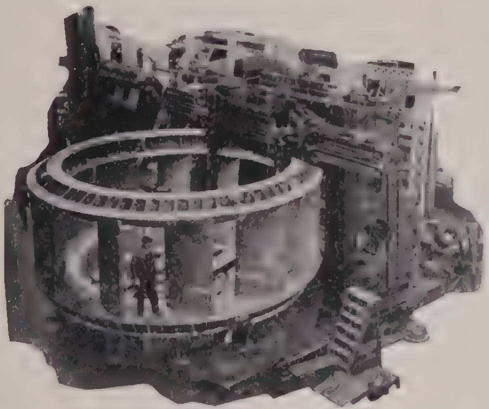

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You Can *Disguise* the Expense of Faulty Lubrication or You Can *Avoid* It

NOT infrequently it becomes necessary to install new bearings in machinery to replace those that are worn down. What shows on the books? "Repairs?" Eventually shafting may get out of line, parts show undue wear, the whole machine goes bad prematurely. "Depreciation?" Dirty oil may drip or be thrown from an overhead shaft. Costly material just happens to get the full benefit. How do you handle the damage? Or, suppose the drip is constant, and oil-soaked wood construction feeds what would otherwise have been a harmless spark. How about the fire loss and the interrupted production? Or a shutdown results from a burnt-out bearing. Is anything to be gained by *disguising* this lubrication expense?

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Schenectady, N. Y.

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THE WAY OF THE PAST

Nature, undirected, will make ice when and where she pleases. But she will not always make it when and where it is needed—in the summer, in the cities, or in the tropics. However, directed by a man-made arrangement of the laws of physics, and with electricity for motive power, Nature will work ungrudgingly to freeze water in an unfailing supply, when, where and in whatever quantity man elects. Compare the scene above with some of those in Mr. McLenegan's article on p. 846

GENERAL ELECTRIC REVIEW

THE VALUE OF ORGANIZED INFORMATION

With this concluding issue of the year 1925, the REVIEW is following its custom of distributing a combination subject and author index that furnishes classified references to the material published during the twelve-month period just closing. This event gives rise to a consideration of the occasion for indexes in general and their service in organizing reference information.

In the case of fiction or general news magazines, the subscriber is usually interested only in the current issue. And having absorbed the portion that attracts his attention he lays it aside, abandoned, and looks forward to the next copy. Thus he would find little or no use for an index to the contents of past issues.

These periodicals whose purpose is to furnish entertainment or a passing knowledge of the weeks' or months' events are important members of the publication family, and no unfavorable comparison is implied when attention is now called to those other magazines that have a more lasting value because they deal with the substantial endeavors of our daily life, and present information that will be constructively useful in these bread-and-butter activities.

For the scientist, the engineer, and the professional man, those magazines relating to his field should be preserved for future reference; and the cost of binding is ordinarily justified by having in shipshape form the information that may be just as useful several years after publication. In fact, the worth of published theoretical treatises on fundamental phenomena usually increases during the process of applying them to practice. Thus an index to back volumes is essential to bring out the full worth of technical magazines.

Industry is beginning to realize that the platitude "There is nothing new under the sun" is more often a reality than not. Many large corporations are maintaining their own libraries in order to have information available and organized for immediate use, by which means they can avoid unnecessary duplication of research effort in fields that have already been explored. Since these manufacturers find worthwhile the maintenance of such institutions and trained workers to administer them, it is obvious that the individual can benefit also in his smaller sphere by organizing his collection of data which for quick access is simplified by an index *and its use*.

How often a person untrained in the pursuit of information is observed to open a book and thumb through it hurriedly back and forth with the expectation of finding the chapter or tabulation he is seeking! Not finding it, although it may be there, he may lay the book aside and try two or three others likewise, finally abandoning the search as of no avail. Except by good luck, he will accomplish nothing but the waste of time by this loose practice, for on failing to find the material sought he is not even certain that it is absent.

Compare this chance method with the scientific method of one trained in the use of books. He immediately consults the index and there discovers the page number of the desired data or, failing to find it indexed, can rest reasonably assured that the book does not contain what he wants—all this with the minimum of time and effort.

As much as an index adds to the value of a book, it adds more to the usefulness of a magazine. The book's logical development of what is usually a single subject is impossible of attainment in the volume of a magazine, for its going to press cannot await the securing and correlation of its total content. Built up at regular intervals by the addition of finished units, each broader in scope than the average book, the resulting volume presents a good chronological development but a haphazard subject arrangement. The index is the logical key to this mixture of subjects.

In our experience as librarians, we find that if one guesses at the date when an article was published he is likely to be wrong anywhere from months to years, and in many instances the magazine in which memory recalls its appearance is not the one which published it. Hence, we strongly urge the cultivation of the "index habit." It will save time and effort; and, what is more important, it will result in a higher percentage of information located.

WILLIAM F. JACOB,
Main Library, G.E. Co.

In connection with the subject of indexes, we call attention to the announcement on the page facing the Table of Contents.—EDITOR.

The Marine Screw Propeller

By C. Macmillan

Induction Motor Engineering Department, General Electric Company

The field of the electrical engineer is no longer confined to the dry land, for there is a great and constantly growing demand for the replacement of marine reciprocating steam engines by more compact and more efficient prime movers for electric propulsion. In presenting this article on the screw propeller, Mr. Macmillan has brought out in a clear way the intricate problems of propeller technique in order that the engineer may gain further insight into the process of transforming rotational mechanical power into useful hydraulic thrust at the stern of the ship.—Editor.

Introduction

Until recent years the development of the screw propeller proceeded in close conjunction with that of the reciprocating engine. This combination of propulsive mechanisms was practically the only one with which marine engineers were concerned, and the main elements in the standardized power equipment were evolved in harmony with their mutual demands.

Modern marine practice, however, includes several alternative types of equipment such as the direct-coupled steam turbine, the direct-coupled oil engine, the steam turbine with mechanical single or double reduction gears or with electric transmission, and the high-speed oil engine also with electric, mechanical or hydraulic transmission gear. The apparatus required for these various types has been adopted for marine purposes after reaching advanced stages of development in other fields, and consequently the marine engineer has become dependent upon the co-operation of the specialists in those fields. However rapidly he may acquire familiarity with the new resources at his command, the co-operation of engineers more familiar with high-speed steam turbines, gears, oil engines, and electrical apparatus, will always be valuable to him, and such co-operation may be rendered even more effective if these other engineers in their turn possess a clearer comprehension of the special problems involved in ship propulsion.

In the following article an analysis of the operation of the screw propeller is given which may assist engineers in forming a clear and plausible conception of the process by which mechanical power is utilized to drive a ship. Such a conception is not easily obtained from the methods which have proved most satisfactory for purposes of successful design and accurate prediction of propeller performance.

The Screw Propeller as a Pump

The screw propeller, or for brevity, the screw, is primarily an axial reaction pump without casing and its main duty is to discharge a column of water astern relative to the ship to which it is attached. If the ship is held stationary, the whole of the rotational power required to drive the propeller shaft is dissipated in the stream of water established. If the vessel is allowed to advance with a velocity of V_a knots a certain portion of the power supplied is usefully employed in driving the ship at this velocity against the resistance which is experienced by the hull in advancing through the water. As an example we may consider the various conditions under which a tow boat operates, assuming a constant rotational speed of the propeller shaft of N r.p.m.

(1) The tow boat may be used to hold a liner against her dock by pushing broadside on. In this case the screw provides a large stationary force, but delivers no mechanical power since the tow boat does not advance. The power of its engine is entirely dissipated in the wake stream.

(2) The tow boat may tow a heavy string of barges at a low speed V_{A1}, exerting a force T_1 on the tow line. In this case a portion of the power is recovered as the useful mechanical power measured by the product $T \times V_{A1}$.

(3) With a much lighter tow we may denote the useful power by $T_2 \times V_{A2}$, in which case T_2 is smaller than T_1 but V_{A2} is greater than V_{A1}.

(4) We may further suppose that instead of towing, this boat is towed by a second vessel of greater power and at such a speed that the thrust block of the first tow boat is relieved of all thrust. We may denote the speed at which this occurs by V_p, since it is determined by the pitch P of the propeller and the speed of rotation N which we assumed as constant throughout.

Flow of Water Through the Propeller

We may now attempt to visualize the conditions in the stream of water flowing through the screw in these four cases, and also imagine any number of intermediate cases involving different values of thrust and speed, so that finally we shall have the complete range from the case of the vessel at standstill, with greatest thrust, to the case in which the thrust entirely disappears at the speed V_p. At standstill the screw delivers a nearly cylindrical stream astern, which gradually converges to a minimum diameter at some point in the rear. In front of the wheel, the water required to maintain the wake stream is drawn from all directions towards the hub of the propeller but before reaching the hub the stream lines all converge into directions nearly parallel to the shaft. The complete stream lines are very similar to those which would be formed by water approaching and issuing from a circular hole in the side of a vessel under pressure. In the latter case the converging stream is maintained by the difference of pressure within and outside of the vessel. In the former the converging stream receives the necessary forces from the propeller blades. In order that the stream may converge, it must be accelerated. Pressure energy must be converted into energy of velocity, and neglecting frictional losses the total energy is unchanged in amount. These statements are equivalent to the Bernoulli equation

$$cp + bv^2 = a \qquad (1)$$

where p is the pressure per square inch and v is the velocity at any section of the stream and c, b, and a are constants.

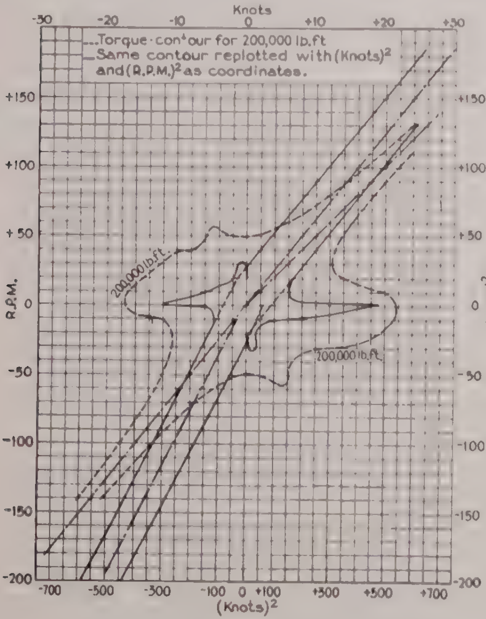

Fig. 1. Constant Torque Contour Curves

(Replotted from Dyson's "The Screw Propeller")

Propeller Characteristics Depend Upon Velocity

When the boat is allowed to advance with velocity V_A a new force is introduced which is proportional to V_A^2. At the stream section in which the propeller operates this new force proportional to V_A^2 relieves the screw of part of its accelerating duty. The velocity necessary to maintain the steady flow through the wheel remains constant. Relatively to the wheel it is always approximately V_p, so we may write equation (1) in the form

$$cp + bV_A^2 = aV_p^2$$
$$\text{or } cp = aV_p^2 - bV_A^2$$

Let O represent the effective area of the screw disc, and let K be such that $K \times O = c$. We may also select constants A and B such that $a = K\ A$ and $b = K\ B$.
Then

$$KOp = KAV_p^2 - KBV_A^2$$
$$\text{or } Op = AV_p^2 - BV_A^2$$

But O_p represents the total thrust T on the propeller; therefore

$$T = AV_p^2 - BV_A^2$$

Fig. 1 is a replot of a torque contour curve (propeller of U.S.S. *Delaware*, from Dyson's "The Screw Propeller,")⁽¹⁾ substituting squared velocities as ordinates. This graph reveals certain characteristics of the propeller more clearly than the original contour, which is shown in dotted lines for comparison.

The deviations from the rectilinear graphs at zero knots represent the breakdown, sometimes termed the vortex condition, in which an increased value of r.p.m. is evidently required to maintain the constant value of torque. The deviations also indicate the substitution of projected area for disc area as the effective area of the propeller. They demonstrate that the propeller without rotation requires increased values of the speed of advance to maintain constant thrust, with corresponding constant values of torque.

Incidentally, the different slopes of the graphs in the first and third quadrants of the diagram show clearly the difference of true pitch of the same propeller when using the face and back of the blade, respectively, to produce positive pressures. The corresponding contours for constant thrust are very similar in form.

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(1) See also Analysis of Propeller Performance, by the author, *Proc. Inst. Engineers and Shipbuilders of Scotland*, Feb. 14, 1922.

Within the limits set by cavitation such contours furnish the complete data of propeller behavior under any conditions of operation when not affected by the proximity of the hull. For specified torque definite corresponding values of $(\text{r.p.m.})^2$ and $(V_A)^2$ are determined. Maintaining the same value of $\frac{V_A}{\text{r.p.m.}}$, the values of torque and thrust for any other value of r.p.m. or V are easily obtained by means of the formula

$$\frac{T_2}{T_1}=\frac{Q_2}{Q_1}=\frac{(\text{r.p.m.})_2^2}{(\text{r.p.m.})_1^2}=\frac{V_{A2}^2}{V_{A1}^2}$$

Examples of graphs deduced from contour curves by these methods are given in Dyson's "The Screw Propeller," pp. 396 to 404, inclusive.

Experiments with model propellers demonstrate that the changes of torque with any given propeller due to changes of thrust are closely proportional to the latter. Therefore the equation for torque, Q, may be in the same form as the thrust equation. Using suffixes to distinguish the constants, we may write

$$T=A_tV_p^2-B_tV_A^2 \qquad (2)$$

and

$$Q=A_qV_p^2-B_qV_A^2 \qquad (3)$$

where Q = torque in lb.ft.×2.12. This is the equivalent force concentrated at the radius of gyration instead of at 1 ft. radius as usually used for torque.

Although there are many secondary considerations which in actual practice modify the simple relations given above, it is nevertheless convenient to retain equations (2) and (3) as the basic expressions for thrust and torque respectively. The graphs shown in Fig. 2, which are replotted from Prof. W. F. Durand's "Researches on the Screw Propeller," demonstrate the advantage of plotting thrust and torque against $(1-s)^2$ rather than against s or $1-s$. The two models selected are those for which tests at zero speed of advance were available, and indicate approximate proportionality between T, Q and $(1-s)^2$ from $s=0.1$ to $s=1.0$.

The simple proportionality between changes of thrust and torque would involve a corresponding proportionality between total thrust and total torque were it not for the incidental frictional forces involved. The same experiments indicate, however, that these may be recognized without seriously affecting the simplicity of the equation. Test results for a given propeller with N held constant may be represented very approximately by an equation of the form

$$T=pQ-q \qquad (4)$$

where p is constant for any speed of the propeller and q is constant for the value of N at which tests are taken.

Propeller Characteristics Depend Upon Shape

In order to compare propellers of different forms it is necessary to specify certain important dimensions and characteristics of each. The most important may be defined as follows:

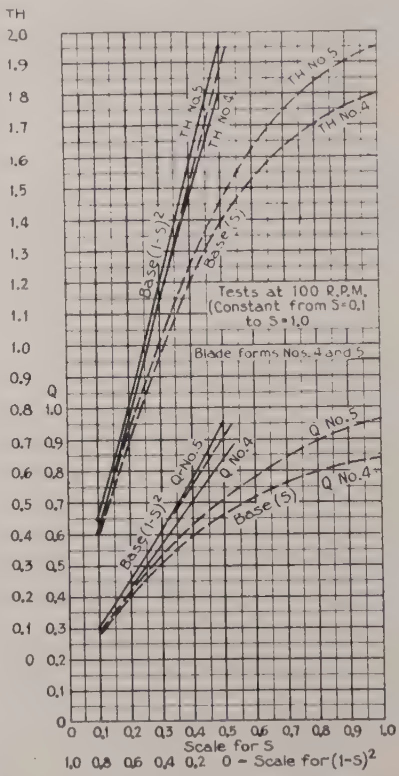


Fig. 2. Graphs of Thrust and Torque on Base $(1-s)^2$

(Replotted from Durand's "Researches on Screw Propellers," Bulletin No. 79)

d—diameter of circle through tips of blades, in feet.

p—geometric pitch in feet. This is the axial distance between successive turns of the helix from which the faces of the blades are obtained.

m.w.r.—mean width ratio, the ratio of the expanded area of one blade divided by the length of blade, tip to hub, relatively to the diameter d.

b.t.f.—blade thickness fraction. The section of the blade in the plane of the shaft is usually bounded by two straight lines which intersect near the blade tip and cut the shaft axis at two points some distance apart. The ratio of this distance to the diameter d is called the blade thickness fraction.

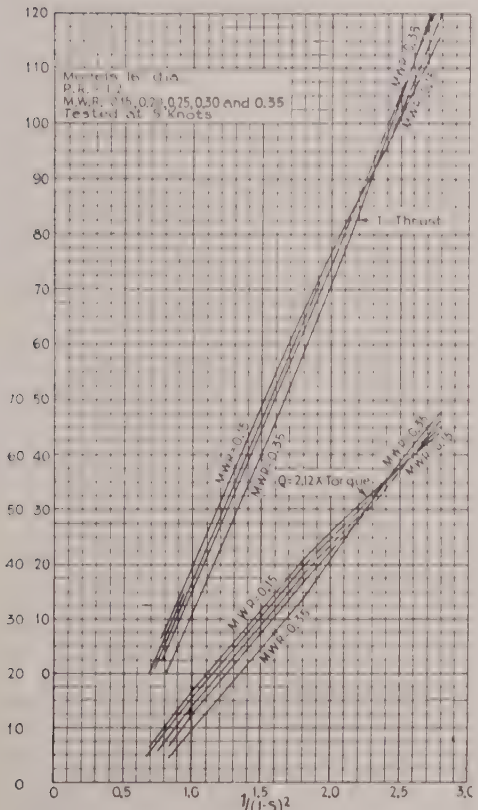


Fig. 3. Graphs of Thrust and $Q = \text{Torque} \times 2.12$
(From Taylor's "Speed and Power of Ships," Vol. II)

d.a.—disk area in sq. ft.

h.a.—helicoidal area—the sum of the expanded or developed areas of all the blade faces, in sq. ft.

p.a.—projected area—area of projection of all blades on a plane perpendicular to the shaft axis, in sq. ft.

Since the blade section is almost invariably ogival, that is, straight on the blade surface with a circular arc on the back, and since the outline of the blade surface usually differs but little from the elliptical form, the values of the quantities defined above serve to specify the form and size of a propeller with sufficient accuracy. The number of blades and the hub diameter should also be stated.

The graphs of Fig. 3 demonstrate the advantage of $\frac{1}{(1-s)^2}$ as abscissas for test results where V_A remains constant. In these examples (from Taylor's "Speed and Power of Ships") the effects of varying blade width and section are clearly visible.

With propellers of similar form, the constants p, m.w.r., and b.t.f. are proportional to d, and d.a.; h.a. and p.a. are proportional to d^2, and to these wheels the laws of similitude are directly applicable when they operate under similar conditions. Such conditions are sufficiently identified when the geometric slip is the same in each case. The geometric slip is most simply defined with reference to the symbols V_p and V_A, where V_A is the speed of advance of the screw in space, and V_p is the speed of advance which would be obtained by calculation from the known r.p.m. and geometric pitch of the screw without allowance for slip. Then the geometric slip

$$S_o = \frac{V_p - V_A}{V_p}$$

By selecting the same value of slip for two similar propellers we are enabled to apply the law of similitude in the form

$$\frac{F_1}{F_2} = \frac{\rho_1 V_1^2 l_1^2 f\left(\frac{V_1 l_1}{v_1}\right)}{\rho_1 V_2^2 l_2^2 f\left(\frac{V_2 l_2}{v_2}\right)}$$

to any corresponding forces where

F_1, F_2—are any corresponding forces applied to or exerted by the two wheels.

V_1, V_2—are any velocities of corresponding points in corresponding directions.

l_1, l_2—are corresponding linear dimensions.

ρ_1, ρ_2—are corresponding densities of fluids.

$v_1\, v_2$—are corresponding viscosities of fluids.

$\left(\frac{V_1 l_1}{v_1}\right)$—is a function which is constant in form for similar wheels. It has been demonstrated by experience that $f\left(\frac{v_1 l_1}{V_1}\right)$ is also constant within the limits of accuracy attainable, so that the formula reduces to

$$\frac{F_1}{F_2} = \frac{\rho_1 V_1^2 l_1^2}{\rho_2 V_2^2 l_2^2}$$

and since there is usually little difference of water density in the cases compared, the factors ρ_1 and ρ_2 may be omitted, leaving

$$\frac{F_1}{F_2}=\frac{V_1^2\,l_1^2}{V_2^2\,l_2^2}$$

Selecting total thrust T as represented by F_1,F_2, diameter d as represented by l_1, l_2, and tip speed of blades V_t represented by V_1, V_2, we find that:

For constant tip speed

$$\frac{T_1}{T_2}=\frac{d_1^2}{d_2^2}=\frac{(d.a.)_1}{(d.a.)_2}=\frac{(p.a.)_1}{(p.a.)_2},$$

for constant diameter

$$\frac{T_1}{T_2}=\frac{(V_{t_1}^2)^2}{(V_{t_2})^2}=\frac{(N_1)^2}{(N_2)}$$

and for constant thrust

$$\frac{(V_{t_1})^2}{(V_{t_2})^2}=\frac{d_2^2}{d_1^2}=\frac{(N_1)^2\,d_1^2}{(N_2)^2\,d_2^2}$$

and therefore

$$\frac{N_1^2}{N_2^2}=\frac{d_2^4}{d_1^4}=\frac{p_2^4}{p_1^4}$$

Since V_p and V_A are also proportional to V_t, we have, with constant thrust,

$$\frac{(V_{p_1})^2}{(V_{p_2})^2}=\frac{V_{A_1}^2}{V_{A_2}^2}=\frac{d^2_2}{d_1^2}$$

$$\text{or}\quad \frac{V_{p_1}}{V_{p_2}}=\frac{V_{A_1}}{V_{A_2}}=\frac{d_2}{d_1}$$

From these formulas we may derive others giving the relations of power and speed, for different dimensions as follows:

$$\frac{T_1}{T_2}=\frac{V_{A_1}^2\,d_2^2}{V_{A_2}^2\,d_2^2}$$

The useful horsepower is represented by $T\times V_A$. Therefore

$$\frac{hp_1}{hp_2}=\frac{T_1V_{A_1}}{T_2V_A^2}=\frac{V_{A_1}^3\,d_1^2}{V_{A_2}^3\,d_2^2}=\frac{V_{p_1}^3\,d_1^2}{V_{p_2}^3\,d_2^2}$$

$$=\frac{N_1^3\,p_1^3\,d^2}{N_2^3\,p_2^3\,d_2^2}=\frac{N_1^3\,d_1^3\,d_1^2}{N_2^3\,d_2^3\,d_2^2}=\frac{N_1^3\,d_1^5}{N_2^3\,d_2^5}$$

Use of Standard Models

By the aid of these formulas or others which may easily be derived from them, the characteristics of any proposed propeller design at any proposed speed may be deduced or estimated from the recorded tests of the most nearly similar standard models. The results are not directly applicable to the full sized propeller when operating behind its proper hull, but must be modified from the results of experience with full sized vessels by some such methods as those developed by Admiral Dyson in his book on "The Screw Propeller." Especial care must be taken that the mere numerical application of the formulas of similitude does not result in such excessive pressures or linear speeds that cavitation occurs. Cavitation sets in when the water pressure at some point falls below that necessary to maintain continuity of flow.

When considering variations in the design of a propeller, or comparing propellers which depart from strict similarity, perhaps the most important case is that in which different pitches are involved, or rather different pitch ratios as expressed by the fraction $\frac{p}{d}$. Without revising the complete design, it is frequently sufficiently accurate to assume that the thrust varies in some cases as the sine, in other cases as the tangent of the effective pitch angle. The latter may be defined as the pitch angle of the blade face at a radius of $\frac{\sqrt{2}}{4}\,d$ or $0.352\,d$.

The conditions which determine the selection of the sine law or the tangent law have not been clearly defined. The tangent law seems most applicable to the finer pitches, including all normal propellers up to a pitch ratio $\frac{p}{d}=1.3$. There are also test results which indicate that for any given speed of rotation the law changes at a certain critical force on the blade whether due to change of pitch or of slip. In any case the difference between the results obtained by selecting either of the two alternatives in comparing moderate changes of pitch is so small that the distinction is not of practical importance.

Effect of Proximity of Hull on Propeller Operation

The foregoing paragraphs furnish a fairly definite conception of the normal operation of a normal propeller, unaffected by the proximity of the hull. Such conditions are obtained in practice in the case of vessels with fine lines, and with the screw set out at a sufficient distance from the hull, and moderately loaded, as for example, in the case of a torpedo destroyer running at three-quarter speed or less.

When the required conditions of speed, power, etc., are favorable, the propeller designer will select those dimensions and proportions with which the highest efficiency can be secured. The most efficient propellers have a pitch ratio $\frac{p}{d}=1.2$ or over. The most efficient number of blades for a given form is two, but this arrangement would usually deliver insufficient power and introduces the risk of objectionable vibration, so that the three-blade propeller offers a most satisfactory compromise. The m.w.r. should be in the region 0.2 to 0.25, giving a value of $\frac{\text{p.a.}}{\text{d.a.}}$ of approximately 0.3. The geometric slip for maximum efficiency is nearly 20 per cent. In order to avoid risk of cavitation, the thrust should be limited to give a thrust pressure not exceeding 10 lb. per sq. in. of "projected" area or p.a., and the tip speed should not exceed 10,000 ft. per min. By careful designing much higher values have been used without encountering objectionable cavitation, but it is not usually necessary in normal design to overstep the limits given above. Heavy loading usually reduces the efficiency even when no objectionable features are apparent and a considerable reduction of efficiency may completely escape notice.

Restrictions Upon Efficient Design

There are two factors which frequently interfere with the free design of the most efficient propeller for a proposed equipment:

(a) The space available at the stern of the ship will not accommodate the diameter of the best wheel, and

(b) The best rotational speed for the wheel is unsuitable for the engines.

To meet objection (a), four blades instead of three or two, may be used, and the m.w.r. of the individual blades may be made as high as 0.35, instead of the ideal value of 0.25. The combination of these two factors may raise the value p.a./d.a. above 0.6, instead of 0.3. This change is always accompanied by a considerable loss of efficiency and the power obtained does not increase in proportion with $\frac{\text{p.a.}}{\text{d.a.}}$ but more nearly as $\sqrt{\frac{\text{p.a.}}{\text{d.a.}}}$

Heavy loading requires increased strength, involving increased blade thickness, with consequent reduction of efficiency. On account of objection (b) it is frequently necessary to resort to fine pitch screws of $\frac{p}{d}=0\ 8$ or less. This is the chief cause of inefficiency in the propellers of standard cargo boats. When considering the effect of pitch ratio on the performance of a propeller it is necessary to remember that the true pitch may be very different from the geometric pitch. The difference is chiefly due to the curvature of the blade back, and is therefore greatest in the case of thick and narrow blades. These behave as if the true pitch were much greater than the geometric pitch. Although a thick narrow blade may imitate a normal blade of greater geometric pitch in its relation of speed and power, the two are not necessarily equivalent as to efficiency, nor does the true pitch of the thick blade necessarily remain equivalent to that of the other over any great range of slip. True pitch is apt to change with large load and slip of abnormal operation, a subject which calls for separate treatment. Propellers of normal design may be said to be in normal operation when running at steady speed, thrust and torque with geometric slip of 5 to 25 per cent. All other values of slip, all unsteady conditions, and all speeds with reversed rotation of the propeller may be considered as abnormal. Many of these abnormal conditions are of practical importance.

Abnormal Operating Conditions

It is useful to have some comprehension of the state of affairs when a propeller starts, stops or reverses a ship, or varies its load rapidly in a rough, pitching sea.

Returning to our example of the tow boat with engines running at constant rotational speed, we may add a fifth case not covered in any of the four already mentioned.

(5) Assume that the tow boat is towing a large and powerful liner whose engines are stopped. Next assume that for some reason the liner starts her engines full speed astern, overpowers the tow boat, pulls her backwards against the operation of her own screw. What will be the effect on the thrust and torque of the tow boat's propeller shaft?

If our basic equations (2) and (3) were exactly and universally true we could obtain the answer directly from them and could plot curves of T and Q against V_A which would give the whole history of the operation, even if the tow boat were overpowered to the extent of being dragged astern at full speed. Equation (2), $T=A_tV_p^2-B_tV_A^2$ would show that in the latter case, when $V_A=-V_{p_1}$, T would be approximately equal to zero (since A_t and B_t are known to be nearly equal, from tests on model propellers).

The actual course of affairs is very different. In the first place V_p, depending as it does on the true pitch of the propeller, is not constant up to 100 per cent slip, and so the thrust at standstill may be considerably greater than

$$V_{p_1}^2-V_A^2=V_p^2$$

These larger values may be maintained up to about 115 per cent slip ($V_A = -0.15\ V_{p1}$). Here a maximum value is reached, and there is a breakdown of thrust to a minimum value at about 130 per cent slip. Then the law of the propeller changes entirely, and above 140 per cent slip the thrust increases almost directly proportional to the slip, and at a rate which is nearly twice as great as that occurring with small slips of 5 to 10 per cent. The curve of torque closely imitates the thrust curve as described above. The unstable range from 110 per cent to 140 per cent has been described as a vortex condition by some writers on the subject. At this stage the front of the propeller is receding from instead of advancing into the water which is furnishing the stream through the wheel. At about 110 per cent slip, or 10 per cent speed in the reverse direction, it becomes easier to obtain the necessary supply from the high pressure region behind the wheel, so the water spills or short circuits from face to back of blade, chiefly over the blade tips. The small circulating mass of water requires much less accelerating force to sustain continuous flow and the reduced accelerating force required from the blades is represented by minimum values on the thrust and torque curves. As the speed astern increases this local circulating water is washed away from the wheel. At 140 per cent slip the wheel is meeting water at velocity 0.4 V_p which it must stop and reject at a velocity V_p relatively to itself in order to maintain a steady flow. At 200 per cent slip or 100 per cent speed astern, the screw exerts a thrust which may be over twice the first maximum occurring at 110 per cent slip. This condition may easily occur in practice. For example, if a fine lined vessel such as a destroyer is proceeding at low speed astern, and the engines are suddenly thrown to full speed ahead the available power will be sufficient to run the propellers up to the same r.p.m. in the opposite direction of rotation and to do this before the vessel has reduced her speed astern to any appreciable extent. The thrust exerted to reverse the ship will then be over twice the steady thrust astern which is maintained by the same value of r.p.m., before reversal.

For brevity we may describe this operation as follows:

V_p constant,
$V_A = -V_P$
$T = 2.0\ T_N$ where T_N is the steady thrust obtained by running at N r.p.m., with the vessel going ahead.

Where sufficient engine power is available, as in the case just described, the complete operation of reversal consists of two stages.

(1) Reversal of propeller:

$$\frac{V_p}{V_A} = +1.0 \text{ to } -1.0$$

(2) Reversal of ship:

$$\frac{V_A}{V_p} = -1.0 \text{ to} +1.0$$

The thrust and torque curves representing operation (2) are of similar type, but different proportions as compared with curves for operation (1). Defining T_N as before, the minimum value of T occurs at standstill and is equal to 0.4 T_N approximately. The maximum value is equal to 1.0 T_N approximately and occurs at $\frac{V_p}{V_A} = 0.5$. At $\frac{V_p}{V_A} = -1.0$, T reaches a value of approximately $T = 2.5\ T_N$.

The changes in stream flow through the wheel when $\pm V_p$ is less than V_A must be conceived as somewhat different from those which occur while $\pm V_A$ is less than V_p. In each case the forces due to velocity V_A tend to establish a cylindrical stream relatively to the wheel, while the forces due to V_p establish a convergent stream. The resultant form of stream depends on whether V_A or V_p is greater. When V_A passes through zero value a condition which has been referred to as the vortex state is established. On the other hand, when V_p passes through zero value, the thrust which it opposes to the stream velocity depends mainly on the projected area of the blades. When a sufficient rotational velocity is imparted to the wheel, the whole disc area becomes effective. This transition has been clearly demonstrated in the case of flat sector discs without pitch at the experimental tank of Messrs. Denny Bros., Dumbarton. When definite pitch is added to the disc so as to form a true screw additional forces are present due to the rotational acceleration imparted to the cylindrical stream in passing between the blades.

The complete characteristics of a propeller during reversal in either direction could be recorded in eight graphs as indicated in Table I.

These same graphs also cover conditions which may be encountered due to pitching of the vessel in rough seas and due to rapid operation of the rudder in the case of twin, triple, or quadruple screw vessels. The graphs have been described relatively to T_N and Q_N, the total thrust and torque at constant speed ahead at N r.p.m. Since different propellers may be designed to deliver the same power at the same r.p.m., and conversely since the same design may be utilized under different rated conditions, it follows that the maximum torque and thrust of a propeller will apparently vary according to the value of Q_N and T_N to which they are referred. This question is of practical importance since there is a widespread belief that certain propellers, otherwise equivalent, show marked differences in their ability to maintain power and speed in a heavy sea. This ability is also affected by blade width as clearly shown in Fig. 3. The reserve value or overload capacity of a wheel seems to depend on both d.a. and p.a., that is to say, primarily on the diameter, and also on the number of blades and blade width. It is, however, doubtful whether the overload limits are ever reached in wheels of normal design. This is one of the questions which might be cleared up by observations on ships equipped with electric drive where even rapid variations of torque may be estimated with very fair accuracy from the ammeter readings.

TABLE I

	Conditions	Graph	Surface of Blades
(1)	$\left.\begin{array}{l}\frac{V_p}{V_A} = +1.0 \text{ to } -1.0 \\ V_A = \text{constant}\end{array}\right\}$	Plot Thrust against $\frac{V_p}{V_A}$	On blade face
(2)	Same	Same	On blade back
(3)	Same	Plot Torque against $\frac{V_p}{V_A}$ (Lbs. at radius of gyration)	On blade face
(4)	Same	Same	On blade back
(5)	$\left.\begin{array}{l}\frac{V_A}{V_p} = -1.0 \text{ to } +1.0 \\ V_p = \text{constant}\end{array}\right\}$	Plot Thrust against $\frac{V_A}{V_p}$	On blade face
(6)	Same	Same	On blade back
(7)	Same	Plot Torque against $\frac{V_A}{V_p}$ (Lbs. at radius of gyration)	On blade face
(8)	Same	Same	On blade back

Thrust Deduction and Wake Allowance

The ammeter readings depend on the combined behavior of propeller and hull. It is therefore important to have some conception of the chief modifications of apparent propeller characteristics due to the presence of the hull. Two of these are of primary importance; the magnitude of each is greater in conjunction with a hull having full lines aft such as those of practically all cargo vessels.

Thrust deduction: Since the immersed hull surface at the stern is near the screw, the suction of the latter is partly exerted on the ship's surface and tends to drag the hull backward. The part of the total propeller thrust which acts in this way is cancelled, since the action and reaction are equal and opposite. In magnitude this thrust deduction may amount to anything from 0 to 20 per cent in practical cases, so that $T_N - t_r = 0.8\, T_N$ where T_N represents the total designed thrust of the propeller with hull absent and t_r represents the thrust deduction. In this case $0.8\, T_N$ denotes the net useful thrust on the hull. (A thrust meter on the propeller shaft would, however, register the total thrust T_N, not $0.8\, T_N$). Evidently the thrust deduction factor, in this case 0.8, is one which lowers the propulsive efficiency in this same ratio.

Wake factor: A moving hull without a propeller, for example, that of a sailing ship, drags a certain mass of water with it which appears as a following wake at the stern. If a propeller revolves in such a wake without thrust it must revolve at lower speed than if there were no following wake. This lower speed would be suitable for zero thrust if the vessel had no wake but advanced at lower speed. In each case the additional number of r.p.m. required to secure the same thrust T and the same torque Q, would be equal, and would require the same engine power. Denoting the speed of the following wake by V_W and the speed of advance of the ship by V_A, the power input to the shaft would be that corresponding to the speed of $V_A - V_W$ for the propeller, but the useful work done on the vessel would be $T \times V_A$, not $T \times (V - V_W)$. The power is therefore used more efficiently. Some of the energy which would have been required to tow the hull at a speed V_A has been recovered by the propeller. In a somewhat similar manner the efficiency of a turbine or turbine pump is increased by the use of fixed guide blades which impart an initial velocity to the fluid in a favorable direction before delivering it to the impeller for acceleration.

This principle has been utilized more fully in recent practice. Successful results have been obtained by equipping ships with definite guide vanes resembling the blades of a stationary propeller which serve to recover some of the power that would otherwise disappear as energy of rotation in the wake. Marked improvements in efficiency are claimed for this type of equipment.

The methods of allowing for modifications due to known or assumed values of thrust deduction and wake factor are very simple. If V_{AS} and T_s for the ship are known the calculations may be based on the data for the propeller alone, selecting a smaller value of $V_{A_p} = V_{A_s} - V_W$ and a larger value of $T_p = T_s + t$ to represent the conditions to which the propeller must conform.

The Circulation Theory

The popular interest aroused by the appearance of the Flettner rotorship has called forth many articles in the technical press, and some of these have included clear explanations of the hydrodynamic principles utilized by the rotating cylinders. These explanations involve the application of the circulation theory to one of the simplest cases. A more complex case involving the same phenomenon is found in the production of propulsive forces by the blades of a rotating propeller. Dr. S. E. Slocum has designed propellers in accordance with the requirements of the circulation theory for which appreciable improvements in efficiency are claimed. These propellers have blades of radially varying pitch with the object of securing maximum efficiency of operation for each blade element.

These methods of design constitute a marked advance in marine engineering, since they bring the design of propeller blades within the scope of mathematical treatment. They do not, however, detract from the value of the process outlined in the foregoing paragraphs by means of which the variations of propeller performance under varying conditions of operation may be studied, whatever the efficiency of the propellers may happen to be.

The test data on propellers designed in accordance with the hypothesis of Dr. Slocum are not sufficiently numerous to furnish a basis of comparison with those of the Taylor, Durand, or Schaffran series of standard models with true helical blades, but it would seem that the methods of the equivalent blade element should be equally applicable to propellers with any blade form of reasonable efficiency.

Conclusion

The foregoing outline does not attempt to insure more successful design or greater accuracy of prediction in dealing with the performance of propellers under the varied conditions which may occur in practice, but it may serve to explain their characteristics more graphically and simply than the methods in common use.

Tie-in Transformer Equipped with Load Ratio Control

By M. H. Bates

Transformer Engineering Department, Pittsfield Works,
General Electric Company

The equipment for controlling voltage through transformer action may be classified into two groups: that which serves to maintain uniform voltage on a circuit of moderate capacity and potential, and that which ties together two circuits or systems of higher capacity and voltage in order that an excess capacity in either will be available to the other in regular or emergency operation. Induction voltage regulators fulfill the first purpose ideally but are inadequate for the second. Consequently, tie-in transformers equipped with load ratio control are employed in the latter service. The following article outlines the various operating principles that have been incorporated in the design of such transformers, and then describes a particularly large unit that utilizes the preferred features.—Editor.

Introduction

The rapid growth in the number of power generating plants and the tying together of large stations has made necessary the voltage regulation of larger blocks of power and also of higher voltages than properly belong in the field of induction voltage regulators.

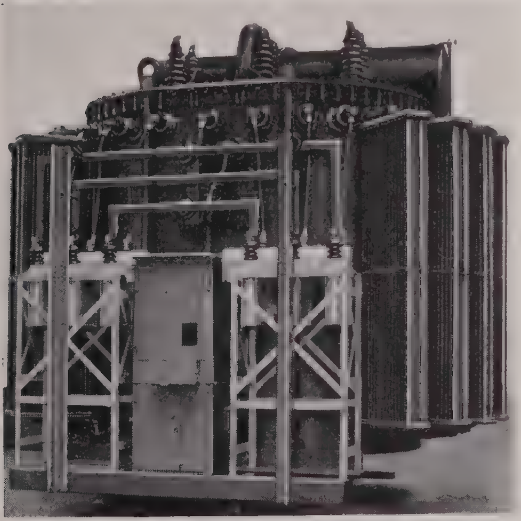


Fig. 1. View of the Low-voltage Side of the 36,000-kv-a. Tie-in Transformer, Showing the Load Ratio Control Mechanism in the Foreground

Three general schemes have been used for tie-in purposes:

(1) The use of various methods of shunting the tap section of the transformer with a reactor while the change in ratio is being made.

(2) The use of two parallel tapped windings in the power transformer itself, each winding capable of carrying the entire load while the ratio of the other is being changed. After the complete operation, the two windings are again in parallel for normal service.

(3) The use of parallel tapped windings in an auxiliary "boosting and bucking" transformer or auto-transformer, the operation being similar to that of the second scheme.

The varied and complicated problems of interconnection necessitate the use of modifications of these schemes. A description will now be given of an installation wherein a combination of the second and third scheme is used.

36,000-kv-a. Tie-in Transformer with Load Ratio Control

The most recent installation of a transformer equipped for ratio changing without removing the transformer from service or interrupting the load is at the Colfax Generating Plant of the Duquesne Light Company near Pittsburgh, Pa. This transformer is of the three-phase core type, rated 60 cycles, 36,000 kv-a., 66,000–59,400Y/72,600Y volts, and acts as a tie between the 66,000-volt system of the Duquesne Light Company and that of the West Penn Power Company. It will make possible the obtaining of 10 per cent buck and 10 per cent boost, each in 9 steps, the resultant voltage being inserted in the tie line. Over a wide voltage range, these systems will thus have a means of regulating the wattless current flowing between them.

The mechanism for changing the ratio of this unit and for operating the oil circuit breakers is practically a duplicate of that which has been in service since October, 1924, on four 20,000-kv-a. units built for the Philadelphia Electric Company.

In detail, the equipment of the 36,000-kv-a. unit for ratio changing under load consists of: two outdoor, cam-operated circuit breakers; a properly timed mechanism with its connecting rod, stuffing box, and intermittent gear; and two five-point star-type ratio adjusters with common neutral.

There are 19 tap positions listed on the name plate. The total time required to operate the mechanism from maximum lower to maximum boost is 36 sec. A weatherproof housing encloses the mechanism and its connection through the main tank, and all the doors are sealed by one lock. The mechanism and circuit breakers are mounted on the same truck as the main transformer, and thus the entire installation may be moved as a unit. The whole unit including the 20 radiators and the oil weighs approximately 75 tons. Fig. 1 shows a view of it completely assembled. Through the opening in the upper housing door may be seen a numbered strip which indicates the tap then in operation. A Selsyn indicator on the switchboard also furnishes the operator with the same information. The mechanism is controlled at the switchboard by a double-throw push button.

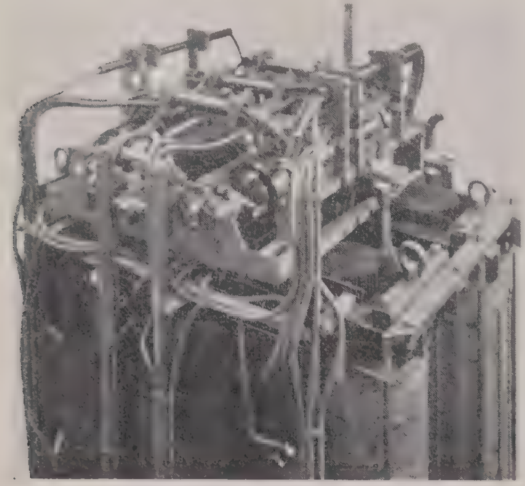


Fig. 2. The Ratio Adjusters and Intermittent Gear as Mounted on the Transformer Cores and Windings and Viewed from the Low-voltage Side

The electrical operation of this auto-transformer is very novel and interesting. For instance, it was considered advisable to place the ratio adjusters, and thus the regulating windings, in a circuit of moderate voltage rather than in the 66,000-volt circuit which is to be regulated as described later.

Fig. 2 shows the arrangement of the internal structure, from which it will be seen that two three-phase cores are used, thus making two transformations of the power. In the diagram of the electrical connections of the unit, Fig. 3, these cores are designated as Core No. *1* and Core No. *2*. Each phase of core No. *2* is identical, and the same is true of each phase of core No. *1* with the exception that one point of the regulating winding (core No. *1*), numbered *10*, is grounded through the tank. The numbered circles in this diagram refer to the terminal lead markings of the actual transformer.

On core No. *1* there are three windings: a 66,000-volt exciting winding Y-connected to one system; a regulating winding delta connected and composed of four equal sections per phase; and a winding which is termed the "Tickler" winding, having a voltage equal to one-half of one section of the regulating winding. There are two sets of five-point ratio adjusters, having three such adjusters in each set. One simultaneously operating set is designated as *M* in Fig. 3 and the other similarly operating set as *N*. The five points of each regulating winding are connected to five points on a corresponding ratio adjuster of each set.

On core No. *2* there are also three windings: a series winding connected directly into the tie line between the two systems; and two equal parallel windings one of which is in series with the tickler winding on core No. *1*.

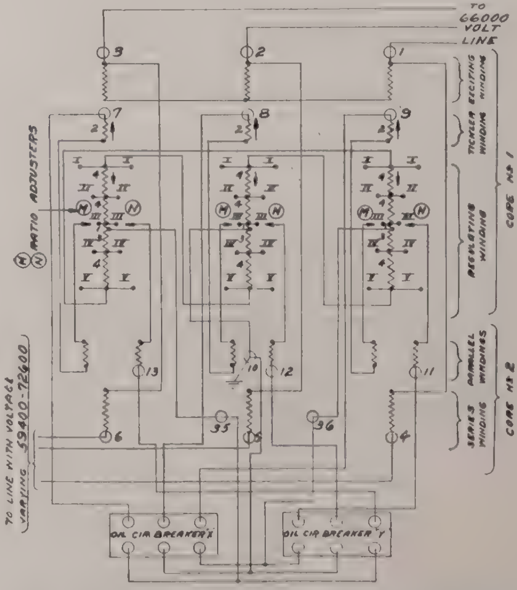
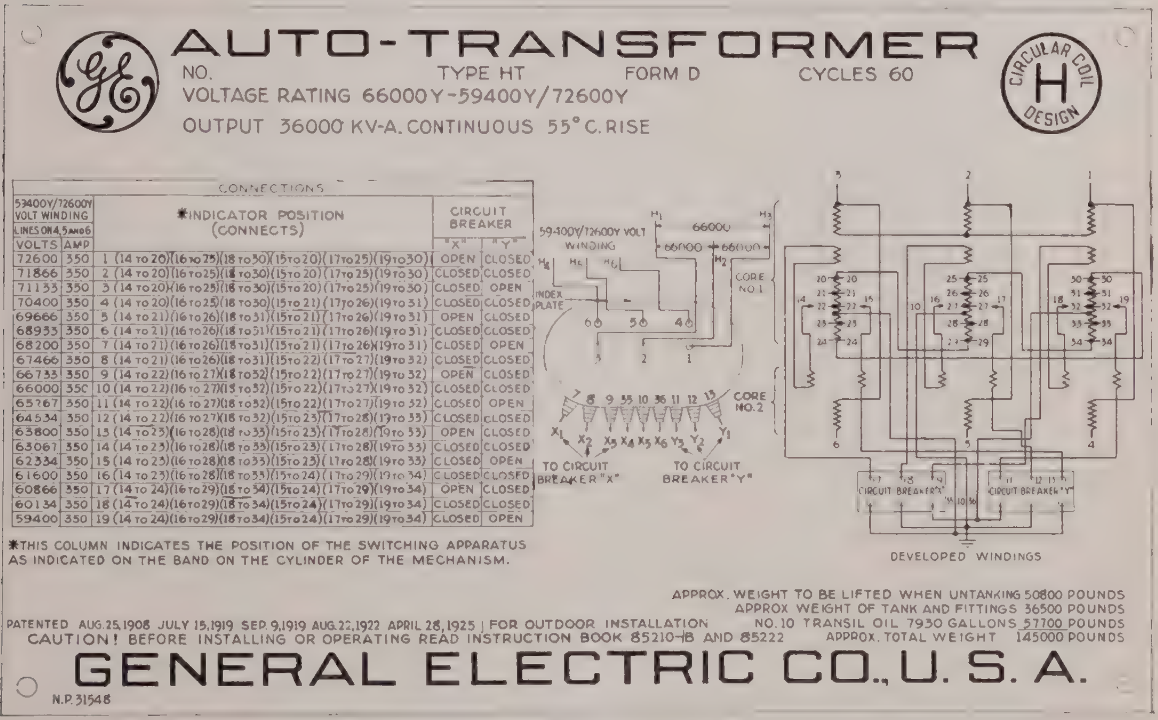


Fig. 3. Wiring Diagram of the Transformer, Showing the Connections of the Series, Parallel, Regulating, Tickler, and Exciter Windings, Also Those of the Ratio Adjusters and Circuit Breakers

Outside the unit there are two 600-amp. 15,000-volt oil circuit breakers designated as

X and *Y*. The neutral point of the *M* adjusters is connected through the tickler winding and one of the parallel windings, and then through circuit breaker *X*. The neutral point of the *N* adjusters is connected through the other one of the parallel windings, then through circuit breaker *Y*. The corresponding outside phase terminals are next joined and this junction carried back to the regulating winding, arriving at a point one-quarter of one section from its middle point. The numbers on the regulating and tickler windings represent the comparative units of induced voltage therein and facilitate an explanation of the different values of buck or boost inserted into the line. The instantaneous direction of the voltages in these windings is indicated by arrows.



AUTO-TRANSFORMER
NO. TYPE HT FORM D CYCLES 60
VOLTAGE RATING 66000Y-59400Y/72600Y
OUTPUT 36000 KV-A. CONTINUOUS 55° C. RISE

CONNECTIONS

59400Y/72600Y VOLT WINDING LINES ON 4, 5 AND 6 VOLTS	AMP	*INDICATOR POSITION (CONNECTS)	CIRCUIT BREAKER "X"	CIRCUIT BREAKER "Y"
72600	350	1 (14 TO 20)(16 TO 25)(18 TO 30)(15 TO 20)(17 TO 25)(19 TO 30)	OPEN	CLOSED
71866	350	2 (14 TO 20)(16 TO 25)(18 TO 30)(15 TO 20)(17 TO 25)(19 TO 30)	CLOSED	CLOSED
71133	350	3 (14 TO 20)(16 TO 25)(18 TO 30)(15 TO 20)(17 TO 25)(19 TO 30)	CLOSED	OPEN
70400	350	4 (14 TO 20)(16 TO 25)(18 TO 30)(15 TO 21)(17 TO 26)(19 TO 31)	CLOSED	CLOSED
69666	350	5 (14 TO 21)(16 TO 26)(18 TO 31)(15 TO 21)(17 TO 26)(19 TO 31)	OPEN	CLOSED
68933	350	6 (14 TO 21)(16 TO 26)(18 TO 31)(15 TO 21)(17 TO 26)(19 TO 31)	CLOSED	CLOSED
68200	350	7 (14 TO 21)(16 TO 26)(18 TO 31)(15 TO 21)(17 TO 26)(19 TO 31)	CLOSED	OPEN
67466	350	8 (14 TO 21)(16 TO 26)(18 TO 31)(15 TO 22)(17 TO 27)(19 TO 32)	CLOSED	CLOSED
66733	350	9 (14 TO 22)(16 TO 27)(18 TO 32)(15 TO 22)(17 TO 27)(19 TO 32)	OPEN	CLOSED
66000	350	10 (14 TO 22)(16 TO 27)(18 TO 32)(15 TO 22)(17 TO 27)(19 TO 32)	CLOSED	CLOSED
65267	350	11 (14 TO 22)(16 TO 27)(18 TO 32)(15 TO 22)(17 TO 27)(19 TO 32)	CLOSED	OPEN
64534	350	12 (14 TO 22)(16 TO 27)(18 TO 32)(15 TO 23)(17 TO 28)(19 TO 33)	CLOSED	CLOSED
63800	350	13 (14 TO 23)(16 TO 28)(18 TO 33)(15 TO 23)(17 TO 28)(19 TO 33)	OPEN	CLOSED
63067	350	14 (14 TO 23)(16 TO 28)(18 TO 33)(15 TO 23)(17 TO 28)(19 TO 33)	CLOSED	CLOSED
62334	350	15 (14 TO 23)(16 TO 28)(18 TO 33)(15 TO 23)(17 TO 28)(19 TO 33)	CLOSED	OPEN
61600	350	16 (14 TO 23)(16 TO 28)(18 TO 33)(15 TO 24)(17 TO 29)(19 TO 34)	CLOSED	CLOSED
60866	350	17 (14 TO 24)(16 TO 29)(18 TO 34)(15 TO 24)(17 TO 29)(19 TO 34)	OPEN	CLOSED
60134	350	18 (14 TO 24)(16 TO 29)(18 TO 34)(15 TO 24)(17 TO 29)(19 TO 34)	CLOSED	CLOSED
59400	350	19 (14 TO 24)(16 TO 29)(18 TO 34)(15 TO 24)(17 TO 29)(19 TO 34)	CLOSED	OPEN

*THIS COLUMN INDICATES THE POSITION OF THE SWITCHING APPARATUS AS INDICATED ON THE BAND ON THE CYLINDER OF THE MECHANISM.

APPROX. WEIGHT TO BE LIFTED WHEN UNTANKING 50800 POUNDS
APPROX WEIGHT OF TANK AND FITTINGS 36500 POUNDS
PATENTED AUG. 25, 1908 JULY 15, 1919 SEP. 9, 1919 AUG. 22, 1922 APRIL 28, 1925 | FOR OUTDOOR INSTALLATION NO. 10 TRANSIL OIL 7930 GALLONS 57700 POUNDS
CAUTION! BEFORE INSTALLING OR OPERATING READ INSTRUCTION BOOK 85210-B AND 85222 APPROX. TOTAL WEIGHT 145000 POUNDS
GENERAL ELECTRIC CO., U. S. A.
N.P. 31548

Fig. 4. Data as to the Adjustability of the Transformer Voltage as Presented on the Name Plate

From the name plate data given in Fig. 4 it will be noted that there are 9 steps either side of indicator position *10*. Therefore, position *1* gives 10 per cent boost and position *19* gives 10 per cent buck, the intermediate positions giving proportional amounts. Consider the previously mentioned figures on the regulating and tickler windings (representing units of boost and buck) to be also equivalent to the number of steps either side of neutral. Following now through one of the tap positions, for instance, indicator position *3* as listed on the name plate and corresponding to 7 units of voltage boost, it will be found that both adjusters are connected to point *20* (on the name plate) located as *I* in Fig. 3. It will also be noted that the *Y* breaker is open. There is then no circuit closed through the *N* adjusters. Following the voltage direction through the *M* adjusters, there will be found four plus four plus one units in one direction against two units in the opposite direction leaving seven units of boost. This is impressed upon the left-hand parallel winding and by induction appears in the series coil. The other two phases act correspondingly.

Now take indicator position *8* corresponding to two units of voltage boost. The *M* adjuster will be seen to be connected to point *21*, or *II* in Fig. 3; while the *N* adjuster is connected to point *22*, or *III* in Fig. 3; also both breakers are closed which allows a circulating current to flow through them, through both parallel windings, and also through the tickler winding and that section of the regulating winding between points *21* and *22*. The average of the voltages on the parallel windings then appears by induction in the series coil. In following through the *M* adjuster there will be found four units plus one unit against two units, in parallel, with one unit boost, which results in an average of two units boost.

Similarly, each position of boost and buck can be determined from Figs. 3 and 4 by keeping in mind the direction of voltages induced in the regulating and tickler windings.

Owing to its large size this unit had to be shipped with its radiators, conservator, leads, mechanism, and circuit breakers removed; the oil, however, covered the core and coils in the main tank.

There are now in service 26 transformers (totaling 345,000 kv-a.) in which load ratio control is secured by utilizing the same principle of electrical connections of the transformer windings, viz., two circuits in parallel. Their performance record confirms the operating excellence of this method of voltage control for the larger blocks of higher potential power.

Direct-current Reclosing Equipments in Industrial Service

By E. L. Hough

Switchboard Department, General Electric Company

It occasionally happens that the child can teach something to the man. Though the man in general possesses the equipment gained through experience and the passage of time, the child's fresher viewpoint often suggests a new angle of attack upon some perplexing problem. This has happened in the case of automatic switching equipment, also. This youth in the family of electrical control has already made a splendid record for itself and is constantly demonstrating its ability to improve service in the tried and trusted fields of industrial electricity. In the accompanying article Mr. Hough tells how the automatic has returned to the dwelling of its progenitor, the manual station, and has there set new standards of economy, protection and unfailing intelligence in emergency.—Editor.

As the development of automatic station control equipments has progressed, various devices and schemes originated primarily for automatic station service have been found to be desirable in attended stations also, and in many cases the application of such devices has given even better results than were anticipated. An outstanding example of this is the direct-current reclosing equipment now being used extensively in the industrial field and particularly in the coal mining industry. When the first automatic substation was started in the mining field there were very few automatic reclosing equipments in coal mines but at the present time it is estimated that there are several thousand in service.

Automatic reclosing equipment makes it possible to increase the plant output without additional power equipment (1) by insuring continuity of power under normal conditions, (2) by giving reliable continuous protection of apparatus, (3) by avoiding mistakes and delays incident to manual reconnection of power and (4) by making possible the more economical distribution of feeder copper, with consequent service improvement. Other benefits will become apparent as the application of these equipments to a particular situation is studied. In some cases it will be possible to dispense with a regular attendant in the station and thus make a direct measurable saving. However, the largest savings accrue from factors that are difficult to express in dollars. To illustrate one of these it is merely necessary to call attention to the normal procedure in a manually operated station and then the operation of automatic reclosing equipment under like circumstances. When a system short circuit occurs which is of a more or less permanent nature in the first case a manually operated circuit breaker is opened and rings a bell alarm to call the attendant from some other work. The attendant, after several reclosures and consequent trippings of the breaker with the resultant wear and tear on substation apparatus, decides that it is a permanent short and waits for notification from the men in the mine that the circuit is clear before closing the breaker again. It is often the case, depending upon the location of the trouble with respect to the station and the available facilities for communication, that this consumes valuable time much of which might have been saved by the use of proper automatic reclosing equipments. If instead of a manually operated breaker an automatic reclosing equipment had been used the breaker would have been reclosed as soon as the short circuit was removed. If the mine trolley circuit had been sectionalized automatically it would have been possible to keep power on all sections except the one in trouble.

Many schemes have been proposed for automatic direct-current reclosing equipments and several are in use. For industrial service, however, the "load indicating" type is used at the present time to the practical exclusion of all others. This type is arranged to "feel out" or measure the load to be obtained on reclosure and thereby prevent reclosures on a load which will cause immediate reopening of the circuit breaker. Two conditions of feed must be met by such a "load indicating" equipment as is evident from Fig. 1. A machine may feed a section of load independently of any other machines. Such a circuit is known as a "stub feeder." When two machines may feed a load simultaneously they are said to feed the load in multiple and the feeders which supply this load are called "multiple feeders." In mining service it is a common practice to have more machines supplying the load during the day than at night and if one machine is shut down at night it can be seen that the feeder becomes a stub feeder. Since this feeder can operate under either stub or multiple conditions it is designated as a "stub-multiple" feeder.

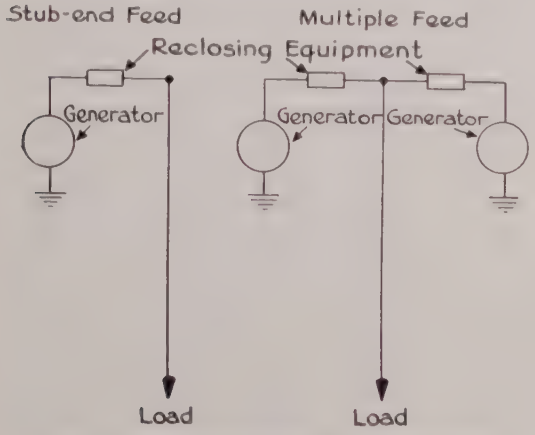


Fig. 1. Feeder Circuits Shown Diagrammatically

Study and experience have shown that an automatic reclosing feeder equipment to suit the conditions outlined should possess the following characteristics:

(1) Trip on overload.
(2) Reclose after a time delay.
(3) Reclose when load conditions become normal.

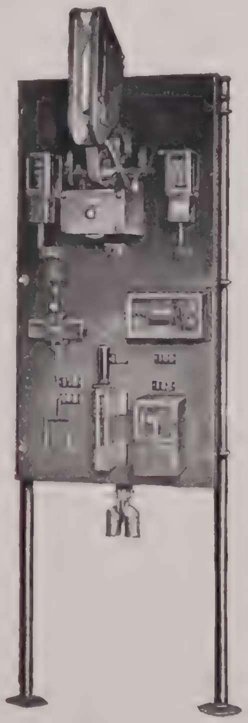


Fig. 2. Direct-current Reclosing Equipment, Stub-multiple Feed

(4) The tripping, time delay, and reclosing values to have independent adjustments.
(5) The reclosing values for stub and for multiple feed to be independently adjustable.

To fulfill these conditions the stub-multiple feeder equipment shown in Fig. 2 was developed. Four years of experience with these equipments in actual service has demonstrated the correctness of the design and the reliability of the component devices.

The overload tripping feature is obtained by a series type overload relay whose contacts open when an overload occurs. These contacts are in series with the coil of the main line contactor and their opening causes the contactor to interrupt the power circuit. The overload relay is calibrated in amperes and may be set at any desired value.

When the line contactor opens one of its interlocks energizes a bellows-type time delay relay which, after the expiration of the time interval for which it is set, allows the line contactor to be reclosed as determined by load conditions. The time delay interposed by this relay is desirable in order to allow an interval for the removal of an accidental short circuit or heavy overload and to allow rotating apparatus to come to rest.

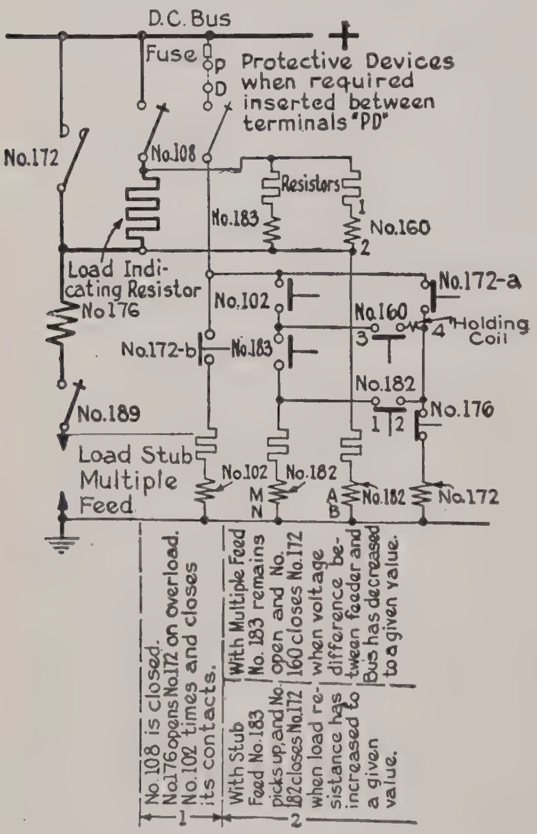

D.C. Bus
+
Fuse
P
D
Protective Devices when required inserted between terminals "PD"
No.172
No.108
Resistors
No.183
1
No.160
2
Load Indicating Resistor No.176
No.102
No.172-a
No.160
3
4
Holding Coil
No.172-b
No.183
No.182
1
2
No.176
No.189
Load Stub Multiple Feed
No.102
No.182
M
N
A
B
No.182
No.172
No.108 is closed. No.176 opens No.172 on overload. No.102 times and closes its contacts.
With Stub Feed No.183 picks up, and No.182 closes No.172 when load resistance has increased to a given value.
With Multiple Feed No. 183 remains open and No. 160 closes No.172 when voltage difference between feeder and Bus has decreased to a given value.
1
2

Fig. 3. Elementary Diagram of the Stub-multiple, D-c. Reclosing Equipment Shown in Fig. 2

In order to determine when load conditions become normal the equipment shown in Fig. 2 makes use of three relays, one for "feeling out" on stub-end feed, one for feeling out on multiple feed, and one to determine under which set of conditions the operation is taking place. The stub-feed reclosing relay may be set to allow reclosure of the feeder at any value of load within the limits of the feeder rating without any danger of the circuit being closed on a short circuit even though the voltage of the circuit varies between wide limits. This feature is obtained by connecting the load-measuring coil of the reclosing relay directly across the load rather than at the center point of the load-indicating resistors. Connection of this relay coil at points other than directly across the load makes it necessary to set the relay to allow reclosure on only a small load in order to prevent reclosures on a short circuit if the system voltage should be high.

On multiple feed the load to be obtained on reclosure depends upon several conditions which are difficult to determine accurately. Some of these conditions are: voltage difference between circuits, feeder resistance, and the amount and location of load with respect to substations. It has been found that a measurement of the voltage difference between the circuits to be tied together is a reliable indication of the load to be obtained on reclosure. A voltage equalizing relay has therefore been used in the equipment shown in Fig. 2 for determining reclosure under multiple feed conditions. A selective control relay is used to select between the stub and multiple feed conditions in order to allow the correct operation in each case.

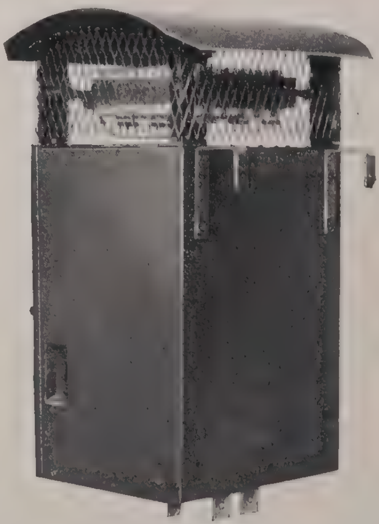


Fig. 4. Exterior View of Automatic Sectionalizing and Reclosing Equipment Cabinet

Obviously an equipment having independent adjustments of the overload, time delay and reclosing values is simpler to understand and adjust than an equipment in which these various functions are interlinked. It can be seen that the equipment described above is provided with separate adjustments for all of these features and in addition is provided with independent adjustments of the reclosing values for stub and for multiple feed.(1)

Irrespective of how well an equipment may appear to be in theory, it is not practical unless it is of a rugged, substantial design throughout. As evidence of the sturdiness of the entire design it is worth while to consider in some detail the main line contactor. This device was developed for steel mill service and is designed to stand hard wear. Its closing coil is designed for continuous full-voltage operation, thus eliminating the possibility of burnouts. The powerful magnetic blowout provides for rapid snuffing of the arc. The interlocks are of simple construction having good rolling contact and wide "break."

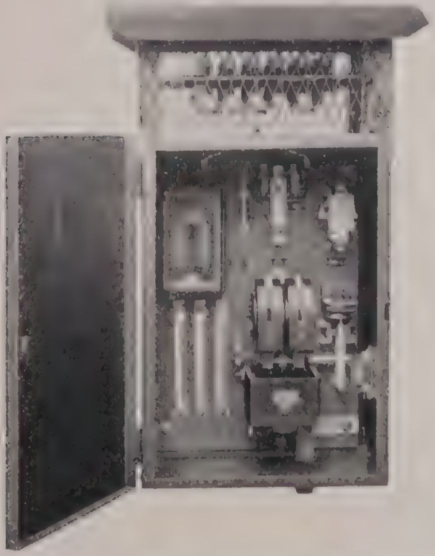


Fig. 5. Automatic Sectionalizing and Reclosing Equipment Cabinet with Door Open to Show Control Devices

The wiring diagram of a stub-multiple reclosing equipment is shown in elementary form in Fig. 3. It will be noted that each device is referred to by a number which designates the function that a particular device performs. These function numbers have been standardized by the Power Club and are now in general use in automatic substation work.

The distribution circuits in factories are usually laid out so that trouble on a single section will interrupt service on the circuit in trouble only and not seriously affect the remainder of the plant. In contrast to this, distribution circuits in mines have generally been tied solidly together or, if sectionalized at all, manually operated lever switches have been used for the purpose. It has long been appreciated that the output of a mine could be considerably increased if the section in trouble was isolated automatically. To perform this service the equipment shown in Figs. 4 and 5 has been devised. This is a self-contained sectionalizing and reclosing unit which operates on stub-multiple feed and will reclose from either side of the circuit depending on which side is alive. The case may be locked to prevent unauthorized persons from tampering yet the circuit may be opened manually by means of a tumbler switch which may be operated without opening the case. All parts are given a non-corrosive rust resisting finish in order to protect the devices in the damp mine atmosphere. In order to allow the equipment to be mounted easily it is provided with mounting hooks similar to small transformer hooks. Since it is obviously not always possible to mount the equipment where men are not liable to come in contact with it the case is arranged for grounding in order to prevent accidental shock. For similar reasons the contactor is completely enclosed to prevent accidental burning from the flash of the arc when the equipment opens a short circuit.

In many mines the working faces have progressed away from the substation so that the feeders are very long and consequently their resistance is high. Often the feeder resistance is so high that a short circuit at the working face will not draw sufficient current to trip the circuit breaker in the substation. The power fed into the short circuit is usually sufficient to cause considerable damage such as burning out of machine cables, controllers, motors and the like, and often sets the entry afire. If automatic sectionalizing equipments are properly used they may be set to open at a value of current which will protect the section. This value is usually much below the setting of the substation breaker.

Within the past few years direct-current equipments have been coming into extensive use in mines because by improving the distribution service they have been found to increase the profits of operation materially. Their utility is not limited to mining however; other branches of industry will, on investigation, find equally serviceable applications for these automatic equipments.

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(1) A detailed discussion by the author of the advantages of this arrangement will be found in *Engrg. and Mng. Jour. Press*, April 4, 1925.

Arc Welding as a Manufacturing Process

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Chairman, Electric Arc Welding Committee, A. B. W.

and

W. Spraragen
Secretary, Electric Arc Welding Committee,
American Bureau of Welding

Any manufacturer of metal goods who seeks to make a better product or one at lower cost will find the means in arc welding. In fact, this process will ordinarily accomplish both purposes simultaneously. The number and variety of its applications already made indicate an apparently unlimited extent of usefulness for this new manufacturing tool. To bring to the attention of engineers, designers, and legislators the possibilities of arc welding in manufacturing processes and the advantages that result from its use, Messrs. Hobart and Spraragen delivered at the fall meeting of the American Welding Society, Boston, October 1925, a review of some of the more prominent applications of which the following is an abstract.—Editor.

The arc weld is a very recent addition to the commercial tools available in manufacturing. To a considerable degree its rather wide applications may be said to have come about as a by-product of the war. Delays in replacing broken, worn, and defective castings, and other parts employed in their products or in the machinery of their systems forced upon industrial managers, railroad executives, and others the necessity of repairing such parts by welding. The intensive, successful use of arc welding in making repairs is leading to the gradual adoption of the process in manufacturing as a substitute for riveting where parts have to be fabricated.

These numerous applications of welding are being brought about through economic reasons, among which may be listed: (1) lower cost of the product, (2) increase of production, (3) improvement in the quality of the product, and (4) the overcoming of manufacturing and other difficulties. In fact, each application listed in this article is the result of one or more of these reasons.

Manufacturers who contemplate introducing arc welding into their shops as a fabricating means must give attention to several fundamental considerations. Of these, the more important will now be stated.

Design

Structures and parts of products which it is intended to weld by the arc process must of course be properly designed to conform to the technique of arc welding in order that they shall effectively withstand the stresses which they will meet in service.

It is a wrong basic principle simply to substitute arc welding for riveting in a structure originally designed for riveting. While such a course can sometimes be justified as a temporary expedient, it is not fair to arc welding to judge it from results obtained in such cases. The product in whose manufacture arc-welding processes are to be employed should be designed with full recognition of this circumstance.

As an example of the need for special designs which recognize the fundamentally different basis of the two methods of joining metals it may be noted that whereas for riveted joints it is necessary to overlap the plates or employ straps, the use of arc welding often permits butt joints to be used. This effects a considerable saving beyond that which could be made by retaining the overlap necessary with riveting.

Material

The material employed should preferably be such as is known to be most satisfactorily arc welded. Thus while arc welding is often applicable to joining cast-iron parts, the art has not yet been so highly developed for such a purpose as for welding mild steel. Experience is being rapidly gained in applying the arc-welding process not only to high-carbon steel and to cast iron, but even to special ferrous alloys, and to non-ferrous metals. But the great mass of the most important and satisfactory applications relates to joining mild-steel parts, such as steel castings, steel plates, and rolled structural steel.

Stresses Allowable in Welded Joints

Adequate care should be taken in determining allowable stresses for the welded joints. In the past, designing engineers who were not familiar with arc welding have been apt to base their determination of the required cross-sectional area of some particular weld on some general limiting value for the tensile strength or shearing strength in pounds per square inch. There are a number of important variables which must be taken into consideration, such as for example: (1) the design of the joint, (2) the chemical composition of the material to be welded, (3) the type of electrode used, (4) the position in which the weld must be made, (5) the general experience of the welder, and (6) the experience of the welder in that particular kind of job.

A steel weld is a steel casting and it is well known that a steel casting will not withstand bending stresses to any such extent as a steel forging of the same tensile strength. This indicates that arc welds withstand tension stresses best. Their ability to withstand shearing stresses comes next in order. The detailed preparation of the parts prior to welding is also very important. The angle of bevel should be suitably proportioned and the surfaces should be free from oil, scale, and rust. It is generally desirable to provide suitably designed jigs or fixtures to hold the pieces in line and in the right plane while being welded.

With a good mild-steel welding wire such as is described later and with plate having an ultimate tensile strength of 55,000 lb., the tensile strength of an arc weld made by a reasonably skilled operator may be taken as 40,000 lb. per sq. in. of weld section. The weld section can usually with advantage be made 10 to 20 per cent greater than the plate section. For fiber stresses in pressure vessels, the safe working stress for arc-welded joints may be taken as about 8000 lb. per sq. in. of the plate section.

The shearing strength of welds may be taken as 36,000 lb. per sq. in. For structural steel work a factor of safety of 4 is suitable. This makes the working tensile stress of arc welds in structural steel 10,000 lb. per sq. in. and the working shearing stress 9000 lb. per sq. in.

Of course, a highly skilled welding operator, even with the materials mentioned, may obtain welds as strong as the original material itself and with special electrodes can produce an arc weld that is stronger than the plate. Although at present there does not exist much data as to the fatigue strength of weld metal, a few tests that have been conducted indicate that one-half of the ultimate tensile strength may be employed as an ultimate endurance limit below which an arc weld will not break for millions of cycles of repetition of stress.

Further Considerations Relating to Carbon Content of the Material

In addition to chemical requirements, there are other properties in steel which are important from a welding viewpoint. With regard to its physical properties, well-made steel is largely dependent upon the amount of carbon in it. This is the first factor to be considered in deciding what chemical analysis should be followed. Other things being equal, the higher the carbon the more difficult is the welding and the less satisfactory is the weld. Of course, the difference in welding qualities is not of much consequence between 0.10 and 0.20 per cent carbon, but there is usually a marked difference when the carbon content exceeds 0.20 per cent. In arc welding, there is localized heating which affects a high-carbon plate to a greater degree than a low-carbon plate. In plates above 0.20 carbon there is apt to be a hard brittle zone next to the weld. Moreover, in arc welds with low-carbon material, the rigidity of the welded joint transfers any bending or vibratory stresses to the parent plate outside the weld and this is more capable of withstanding such stresses. But in high-carbon material the bending and vibratory stresses will not be so effectively diverted from the welded joint to the parent plate.

Welding Wire

Good welding wire, in so far as chemical composition is concerned, may be ensured by following the American Welding Society's specifications.⑴ Chemical composition, however, is not a complete criterion. For example, wide variations in the chemical composition of the deposit are obtained when welding wire of identically the same composition is deposited in the weld by the electric-arc process. The physical structure and the gas content appear to exert considerable influence on the result. However, the phenomena are still far from being understood. A simple test of welding wire additional to the chemical analysis can be made by laying a piece on an iron table and melting it half way through with a gas welding torch. Good welding wire can be distinguished (1) by the ease and smoothness with which it melts, (2) by the evenness and smoothness of the melted surface, and (3) by the lack of sparks. Wire that sparks badly leaves a rough porous surface after welding, and wire that does not flow freely and smoothly is unsuitable for welding. A similar test may be made on the steel to be welded by running the torch flame so as to cut a depression in the steel. If the surface is rough and shows small blowholes it is an indication of unsuitability for welding.

Electric Current Test for Welding Wire

The melting test may also be conducted with electric welding apparatus by "freezing" one end of the electrode to the work or plate, using the normal welding current for the size of the wire involved. By keeping the wire in direct contact with the plate it will reach a uniform melting condition, but if the current is too high the wire will melt close to the plate only and not present sufficient melted surface for observation. It is therefore

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⑴ Bulletin No. 2, American Welding Society.

necessary to adjust the current so that the wire heats up slowly throughout its entire length.

Jigs and Fixtures

The application of arc welding as a fabricating process can in most instances be made more economical and successful through the use of suitable jigs and fixtures. For quantity production very thorough consideration should be given to this aspect of the process in order that full advantage may be taken of the economies in time and labor which may thus be rendered possible. This point is illustrated in a number of the applications of arc welding described later in this article.(2)

Testing the Skill of Operators

With the proper control and assuming conscientiousness and reasonable skill, the quality of a given product is fairly independent of the operator. On the other hand, he must be experienced in depositing the metal in the way most appropriate for the particular job in hand. The expertness of the operator can in most cases be determined only by physical tests to destruction of test specimens of the work which he is doing. Once the welder has proved himself competent to do a particular job, it rests upon the supervisory and inspecting force to see that the quality of his work is maintained.

On the other hand, great care should be taken not to destroy the initiative of the welder. The welder should not be ignored if he complains about conditions not being right. His complaint should be carefully investigated, as sometimes materials which have been accepted by the purchasing department are nevertheless not suitable for the work in hand.

It should also be pointed out that while some welding operators can do a 100 per cent job on certain work, they are entirely unfitted for other kinds of work where it is not apparent that any greater skill is necessary. For example, a man who through long experience can weld thin steel in a flat position may not be able to do it in an overhead position. Again, he may not be able to weld thick steel plates even in a flat position. In another instance a welder who is an expert on repair work may be entirely unsuitable, without additional training, for production work on steel.

Many experts in the welding field recommend periodical tests of sample welds to check the skill of their welding operators. The testing should be done on the kind of work which the operator is performing. Where facilities for testing welded samples are not available, local arrangements can usually be made with a commercial laboratory on a reasonable basis.

Inspection

Inspection of welded products must differ somewhat according to the nature of the work involved. Certain fundamental principles can however be laid down as universally applicable in arc welding.

The importance of proper inspection and supervision cannot be over-emphasized. Almost every article and book written on welding prior to the last few years, directly or indirectly, has implied that the quality of the product was 90 per cent dependent on the skill of the welding operator. With the methods generally in vogue up to the last two or three years this statement was probably fairly correct, as in most cases the selection of material, the design, and the technique of the work were left to a considerable extent to the welding operator. Under these circumstances, it would have been even more correct to state that the quality of the job was 100 per cent dependent on the welding operator. When the problems of material, design, and technique are worked out in advance, the welding operator is called upon only to manipulate the electrode to do a particular job. Relieved of these other responsibilities the operator can, after a little training, be depended upon to do the work day in and day out with less percentage of variation in quality than is found in riveting. This, of course, presupposes the existence of a competent inspecting and supervisory force.

This supervising and inspection service should include:

(1) The provision of suitably designed and constructed jigs and fittings

(2) Checking whether all the requirements are fulfilled as to preparation before welding

(3) Whether suitable materials are being used

(4) Checking the method of deposit of the metal

(5) Whether the proper current is being used

(6) Whether the correct size of welding wire is being used

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(2) Another example of a specific application, viz.: Pipe Welding, is given in "Helping the Pipe Welder," by C. Roy Price, *Welding Engineer*, Nov., 1924, p. 34, and Dec., 1924, p. 34, "Helping the Pipe Welder," Part II.

(7) Whether the actual manipulation of the electrode is satisfactory
(8) Whether the parts to be welded are clean and free from foreign matter
(9) Whether the proper penetration and fusion are being obtained.

In some cases it might be desirable to have the welding operator stamp his number on the job, and in still others the inspecting force might test parts of the work to destruction.

Testing the Finished Product

The greatest handicap to welding is stated by many authors to be that we have no satisfactory non-destructive test available to check the quality of the weld. Many conservative engineers argue that after a job is finished it is impossible to know with certainty whether it is a 50 or 100 per cent strength weld. Proponents of welding in turn answer that it is equally impossible to know the strength and quality of a finished riveted joint, the only difference being that we have grown accustomed to be satisfied with a visual inspection of a riveted joint instead of requiring a test to destruction. This is because riveting has been with us for a long period, the processes have become standardized, and we have learned from experience to place confidence in the product.

This same psychological process is taking place with arc welding. However, whereas the riveting art has been practiced for centuries, we have been using arc welding extensively for a matter of only seven or eight years.

As implied indirectly in previous statements it should be pointed out that the quality of the finished job can be determined in advance, if proper material is used, proper design and technique is employed, and if there is in force a system of regularly checking the skill of the welding operator as to his ability in manipulating the arc.

The most suitable ways of testing welds and welded products are different for every industry. They depend upon the nature of the particular problem in hand. In some cases hydrostatic pressure can be applied with an intensity sufficient to allow a reasonable margin over the stresses that the particular product will meet in service. Penetration of oil, or bubbles from a soap solution, reduction of air pressure, and blows with a hammer are also useful tests for certain classes of work. But in the great majority of cases tests of this sort are neither possible nor desirable.

Cost Data

A quantity of information now exists on the cost of electric-arc welding and in a number of industries comparisons between riveting and arc welding are available. As pointed out in the introductory remarks, a later portion of this article will be devoted to examples of applications of arc welding and comparisons as to the relative cost and quality of product with previous forms of fabrication, such as riveting.

In one industry, viz., that of shipbuilding, considerable information exists. Tables and charts have been worked out in detail which enable draftsmen and engineers to readily compute the cost of doing a particular job.(3) (Similar charts based upon experience should be worked out for other industries.) A leading authority(3) in shipbuilding estimates that in the construction of a ship's fittings and in hull construction, savings ranging from 15 per cent to 25 per cent may be effected. The application of welding to ship's fittings is already extensive. But the conservatism of shipbuilding concerns has restricted the use of welding in joining the hull plates, to a few small vessels all made by different firms and the cost of these first applications has of course always been high.

Speed of Arc Welding

The data given in various text books and papers as to the speed of arc welding are very conflicting. There are so many variables as to make any general statement impossible. The following review will throw light on the matter:

There are automatic arc-welding machines which make long seams at several times the speed possible with hand welding. From the data at present available the speed of making such seams in thick plates (say ½-in. thick) is two or three times as great with an automatic machine as with hand welding. With thin material (say ⅛-in. thick) the speed with the automatic machine is from five to ten times as great as by hand. Time is lost in changing electrodes and in adjustments of position. Moreover, the hand operator becomes fatigued while the automatic machine does not.

Material up to and including ¼-in. thick is being successfully butt welded unbevelled on automatic machines. It is not generally realized that the angle of bevel greatly affects the speed. The authors once conducted a series of tests on the hand welding of ½-in. ship plate. Among many other experiments made in the course of these tests, four samples of butt welds each 3 ft. long were welded by the same operator. The total angle of opening formed by the bevel on the plates being welded in the four cases were 30, 60, 90, and 120 deg. respectively. The welder deposited metal at about 1.75 lb. per hr. in all cases.

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(3) "Applications of Arc Welding to Ship Construction," by E. H. Ewertz, Bulletin No. 6, American Welding Society.

It took so much more metal to fill up the 120-deg. bevel as to reduce the speed of welding to only 1.07 ft. per hr. as against 3.22 ft. per hr. for the 30-deg. bevel.(4)

It is interesting to note that for all four bevels in this investigation, the rate of deposition of electrode was a matter of 0.65 lb. per kw-hr. at the arc on the basis of a 20-volt drop at the arc. One kilowatt-hour is equal to 860,000 calories; 136,000 calories will melt a pound of mild steel. Therefore if all the energy in the arc were used up in melting electrode material, 6.3 lb. ought to be melted per kilowatt-hour at the arc, i.e., about ten times the amount actually melted. But part of the energy in the arc is required to heat and melt the surface layers to be joined; part may vaporize some of the steel; and part is lost in conduction, radiation, and convection. Even at this late period in the development of arc welding, enough advanced physical research of the fundamental phenomena has not been made to allocate even approximately the 90 per cent of energy not consumed in melting the welding wire.

Apparently, some very exaggerated ideas are common as to the amount of metal which can be deposited per hour in practical high-grade arc welding. Some years ago one of the authors of this article published the statement that for hand welding an operator can in the case of the hull plates of ships deposit about 1.2 lb. of metal per hour when working out in the open (as on ships) amidst many inconveniences, as against about 1.8 lb. per hour in the shop. Confirming this it can be seen from the General Electric Company's report in the latter part of this article that, based on the average for a month, for all sorts of work the rate of consumption of electrodes was 1 lb. per welding operator per hour. This would probably correspond to nearly 2 lb. during actual welding. In melting 13,500 lb. of welding wire some 36,000 kw-hr. were consumed, or 0.375 lb. per kw-hr. from the supply circuit. But this very probably corresponded to some 0.6 to 0.7 lb. per kw-hr. *at the arc.*

As an experiment, a 12-ft. cube tank of ½-in. steel was arc welded in 1918. The total time of actual welding was 165 hr., and this corresponded to using up electrodes at the rate of just 2 lb. per hr. The energy consumed at the arc was about 500 kw-hr., and 334 lb. of welding wire was used, of which 299 lb. was deposited in the welds. There was thus deposited 0.60 lb. per kw-hr. of energy at the arc. In making this estimate it has been assumed that the current was 167 amp. and that the pressure across the arc was 20 volts.

TABLE I

Current Amp.	Volts at Arc	Speed of Welding Ft. Per Hr.
165	15	110
195	16	135
200	18	180
220	18	200

In place of stating welding speed in feet per hour, one of the authors in 1919 expressed the following view with which we now fully agree:

"The practice heretofore customary of stating the speed of welding in feet per hour has led to endless confusion as it depends on the type of joint, height of weld, and various details. A much better basis is to express the speed of welding in pounds of metal deposited per hour. Data for the pounds of metal deposited per hour are gradually becoming quite definite. The pounds of metal per foot of weld required to be deposited can be readily calculated from the drawings or specifications. With the further available knowledge of the average waste in electrode ends and from other causes, the required amount of electrode material for a given job can be estimated."(5)

For overhead welding or for welding in difficult places, the speed of deposition is much lower than the value of 1 lb. to 2 lb. per hr. This is also true when, instead of mild steel, some other material is to be joined.

We have seen records of butt welding with automatic machines where long seams in ⅜-in. and ½-in. plates have been welded at 15 and 12½ ft. per hr. with a consumption of 6½ lb. of welding wire per hour. The angle of bevel was 30 deg. and the current from 250 to 300 amp. It is however more usual for automatic welding of butt seams in ½-in.

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(4) Much interesting data on this investigation are given in Pender's "Handbook for Electrical Engineers," in a table on p. 1955.

(5) "Welding Mild Steel," by H. M. Hobart, *Trans. A.I.E.E.*, Feb. 19, 1925, Vol. XXXVIII, p. 63.

plate to estimate on speeds of only 4 to 8 ft. per hr. of actual welding, as against somewhat under half these speeds for hand welding.

Very high speeds are obtained when arc welding quite thin material on the automatic machine. The precise values vary with the size of electrode and with the current. As an interesting example of an attempt to study the influence of the current, Table I is included to show the results obtained in butt welding 14 gauge material with ⅛-in. dia. welding wire.

In 1924, the data in Table II were published with the statement that "these figures are actual welding speeds and will be modified on production work by idle time, preparation, etc."(6)

TABLE II

RATE OF TRAVEL (BARE METALLIC ELECTRODE)

Thickness of Plate In.	Feet Per Hour (Butt Weld)		
	Hand Welding	Semi-Automatic Welding	Full-Automatic Welding
3/32	10	20 to 40	75 to 150
⅛	7½	15 to 30	40 to 75
3/16	6¼	12 to 24	25 to 50
¼	5	8 to 16	15 to 40
⅜	2½	5 to 10	6 to 12
½	2	2½ to 5	3½ to 7
¾	1¼	1¾ to 3½	2½ to 5

The speeds in Table III, in terms of pounds of metal deposited per hour, are recommended by the authors for estimates on the arc welding of mild steel by hand.

The speeds in Table III are such as can be maintained by a fairly skilled welder during an eight-hour day and under favorable conditions, such as welding in the shop. The plates to be welded are assumed to be laid flat and at a convenient height for the operator. It is also assumed that the edges have been prepared and that the plates are clamped and all ready for welding. For vertical welding, these figures should be multiplied by 0.9. For overhead welding, they should be multiplied by 0.7. For work in the field, where the arc is not protected and the welder subjected to inconveniences, these figures should be multiplied by 0.7.

TABLE III

Thickness of Plates In.	Diameter of Electrodes In.	Approximate Current Amp.	Pounds Deposited Per Hr.
⅛	⅛	100	1.4
¼	5/32	150	1.7
⅜	5/32	160	1.8
⅜	3/16	200	2.2
½	5/32	175	2.0
½	3/16	225	2.4

EXAMPLES OF ARC WELDING APPLICATIONS

Locomotive Parts

Arc welding of tubes in boilers is standard practice on several large railroads. The length of service of locomotive boilers before leakage commences is thereby increased from three or four months to three or four years.(7)

Welding Pipe Lines for Oil, Gas, Water, Steam, and Dredges

A permanent non-leak joint as well as a cheaper and better job may be obtained by the use of arc welding on all sizes of pipe lines. Miles and miles of welded pipes, varying from small to very large diameter and from very low to very high pressures have been successfully arc welded. They have given satisfaction in service and in a number of instances a saving as high as 25 per cent may be effected over screwed or flanged joints. Angles, ells, tees, and other fittings may be economically welded.(8)

Well Casings

Welded oil-well casings have been constructed for oil fields of Southern California. The electric arc has proved its efficiency in the handling of large sections and in simplicity and economical production methods. The particular casings were of 13-in. diameter and made of No. 10 gauge iron. It was of two-ply and built in 30-ft. sections, each section consisting of ten 3-ft. lengths.(9)

Rail Joints in Street Railway Tracks

Nearly all joints in tracks in paved streets are now made by some process of welding for which the electric arc is used extensively. The Welded Rail Joint Committee of the American Bureau of Welding is at the present time devoting attention to possible improvement in making the seam-welded type of rail joints. An improvement of 25 per cent in the life of the joint, which is confidently expected by the committee, will result in a saving of millions of dollars annually to the street railways of the country.(10)

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(6) "Arc Welding and Cutting Manual," Publication No. Y-2007 of General Electric Company.

(7) Details of the application of arc welding to locomotive boilers are given in "Welding Tubes in Boilers," by B. C. Tracey, *Journal of the American Welding Society*, March, 1922, p. 35.
Also "Electric Arc Welding on the Steam Locomotive," by W. M. B. Brady, GENERAL ELECTRIC REVIEW, October, 1924, p. 687.

(8) "Applications and Tests of Large Diameter Electric Welded Pipe," by J. H. Nead and R. L. Kenyon, *Journal American Welding Society*, April, 1922, p. 21.
Further information on the subject appears in "Welding Pipes and Fittings," *Welding Engineer*, September, 1923, p. 19.

(9) The details are given in "Arc Welded Well Casings," *Welding Engineer*, April, 1924, p. 19.

Storage Tanks

A number of small and large storage tanks for holding oil, water, and gas have been completely constructed by electric-arc welding. In other cases tops and bottoms only have been welded. Literally thousands of welded tanks have been constructed in various parts of the world, varying in size from a few gallons to gas holders of 2,000,000 cu. ft. capacity, 200 ft. in diameter and 130 ft. high.(11) Not only have there been substantial savings in the construction cost (from 10 to 25 per cent), but still larger savings in tanks for holding oils and gases. The welded construction reduces evaporation and leakage to a minimum. For lighter oils this saving is an appreciable item as compared to the leakage and evaporation from a riveted tank and may equal in a very few years the total cost of the welded tank.(12)

Ship Construction

Allusion has already been made to the great field for arc welding, not only in the fittings of ships, but in joining the hull plates. For fittings, the use of arc welding is increasing rapidly. But as a method of joining the hull plates the only applications have been to a few relatively unimportant ships, a list of which is given later in this section of the article. Although the plan of using arc welding instead of riveting for joining the hull plates of ships has been reported upon favorably many times by men of unquestioned authority, wide experience, and mature judgment, the use of riveting for this purpose appears to be so strongly entrenched that it is not likely to be replaced by welding on any considerable scale in the near future. For oil tankers there is with arc-welded hulls the additional advantage of oil tightness. But for steel hulls for any purpose arc welding offers the following advantages: (1) saving of material, (2) saving of labor and (3) increased seaworthiness.

There are several classification organizations such as Lloyd's Register of Shipping, and the American Bureau of Shipping, which have published lists of items in ship construction where arc welding may be employed without obtaining special authorization from the approving and inspecting organization.

Many minor and non-structural items and important fittings in merchant vessels, destroyers, and submarines are now regularly arc welded. The following are examples of applications in this field:

(1) *Fittings* that are of an important character, such as continuous railing rods, sky-lights, stairs, gratings, ladders, coal chutes ventilator cowls, stacks, funnels, uptakes, bulkheads (which are not structural parts of the ship), tanks, hand rails, deck houses not covering unprotected openings through weather decks, battery and storage boxes, trap seating, holders for boiler spare parts, drip pans, conning tower hatches, ventilation and exhaust pipes, torpedo doors, periscopes, and ammunition scuttles.

Fittings that are of a minor nature such as lashing pads for torpedo tubes on deck, boat chocks on davits, sockets for hand rails, cable and fixture hangers, cable guards, bucket stowage, pipe supports, berth supports to frames, pipe hangers, leaders on deck for steering cable, chocks under turbines and gear cases, hangers for operating rods, pads for all purposes, bars on escape hatches, cargo batten cleats, protecting angles around manholes, seatings for fire extinguishers, brackets, and waterway bars.

(2) *Clips* for jack rods on galley house, ram rods, stanchions, work benches, battery lockers, stores for paints, oils, provisions, electric galley, torpedo magazines, oil burner rack, oil racks, transoms, gauge boards, lathe and grinding stones, ladders, engine room flooring supports, table, cable hangers, bulkheads, detachable rail stanchions, shelving, and lockers.

(3) *Foundations and Supports* for oscillator, bulkheads, battery hatch, torpedo slides, guns, starting flasks, switchboards, engine and boiler room floorings, discharge manifolds, oil tanks, wash machines, compass, diving, and steering gears.

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(10) For further information reference should be made to Progress Reports Nos. 2 and 3 of the Welded Rail Joint Committee, American Bureau of Welding.

(11) Full descriptions of the methods of construction used in the larger tanks are reported in various issues of the *Journal of the American Welding Society* and in the *Welding Engineer*, April, 1925, p. 38.

(12) Report of the American Bureau of Welding's Committee for the "Electrical Welding of Storage Tanks," *Journal of the American Welding Society*, Dec., 1922, p. 16.

Further applications of arc welding in this field are given in "Communication," by E. J. Rigby, October, 1922, p. 25; "The Application of Electric Welding to Large Tank Construction," by E. J. Rigby, August, 1923, p. 14; "Electric Welding of Large Storage Tanks," by H. C. Price, June, 1924, p. 11, all in the *Journal of the American Welding Society*.

Also "Welding Oil Storage Tanks," May, 1923, p. 25; "Arc Welding Gas Holders," by J. N. Reesom, Sept., 1923, p. 25; "Welding Large Storage Tanks," by H. C. Price, Sept., 1924, p. 32; and "Welded Crowns for Gas Holders," June, 1925, p. 29, all in the *Welding Engineer*.

(4) *Attaching* deck rail stanchions to plating, deck collars around ventilators and funnels, cape rings, galley fixture to plating, bath and other fixtures, cowl supporting rings, engine and boiler room stairs and gratings to plating, cleating to casing, door frames to casings, airtight shoes to bulkhead.

The authors have records of seven electrically welded ships. These may be briefly mentioned as follows:

1915—The *Dorothea M. Geary*, 42 ft. long and 11 ft. beam, was launched on Lake Erie. The hull plating was butt welded by the electric-arc process.(3)

1918—The British Admiralty's cross-channel barge *Ac1320*, 125 ft. long and 16 ft. beam, and of 200 tons deadweight, was completely arc welded.(3)

1919—A barge 65 ft. long and 13 ft. beam was arc welded at Caen in France, the welding all being done by women.

1920—The *Fullagar*, a 500-ton coaster of 150-ft. length, built by Messrs. Cammell, Laird & Co., was launched at Birkenhead. The hull plates were joined entirely by arc welding.(3)

1920—A tugboat of 52½ ft. length and 13½ ft. beam was arc welded at Gothenburg in Sweden.

1920—The *Sea Hornet*, a motor boat 58 ft. long with a 600-h.p. engine, a speed of 35 knots, and a cruising radius of 800 miles, was launched from the shipyard of Kyle and Purdy, City Island, New York, N. Y. Electric arc welding was used throughout for all joints. Butt welding was used throughout the shell, this having the advantage of providing a smooth surface and decreasing the hull friction.(3)

1924—An oil barge 76 ft. long, 21 ft. beam, and 11 ft. in depth was built and launched at Providence, R. I. Electric arc welding was used for all joints.

These seven ships are all, so far as the authors have learned, still giving satisfactory service.

Mention should also be made of the attachment, by arc welding, of anti-submarine bulges to the hulls of battleships. The shell plates of these bulges were also joined by arc welding. The construction of such bulges involves more feet of welding and the use of thicker plates than the hulls of fair sized ships.

Arc welding of practically all joints was used in a steel self-floating caisson for a 460-ft. dry dock at the Hikoshuma Dockyard. Another Japanese enterprise was the arc welding at the Kobe plant of a floating crane pontoon 65 ft. long and 35 ft. beam.

At the Norfolk Navy Yard a battle towing target 172 ft. in length was completely arc welded in 1920.

Several ships of considerable size have had portions of their hulls arc welded with a view to gaining experience. Among these may be mentioned the conversion of the steam trawler *Dairyo Maru* into a 300-ton deadweight oil lighter in 1920, and the *Hisco*, a 1200-ton oil barge, in which 60 ft. of the midship section was arc welded.(3)

Arc Welding in the Construction of Steel Buildings

The most recent example of this type of construction is a 40 by 60 ft. mill-type building, Fig. 1, designed and built of scrap structural steel by the Chicago, Burlington, and Quincy Railroad.(13) Many of the steel pieces were heavier than necessary, and were used simply because they were available in the scrap pile and not because any additional size was necessary over the same joint riveted. The saving in the cost of building this structure by arc welding was 41 per cent of the cost of a riveted structure.(14)

Architects have not yet acquired sufficient confidence in the arc-welding process as a means of fabrication to adopt it for large buildings. Also, from what has been said in the first part of this article, it will be understood that a competent supervisory force must be available in addition to the welding crew. There is undoubtedly necessary a new type of technical training, viz., welding engineering, and perhaps one good way to advance welding would be to interest various engineering schools to teach welding as a science in addition to the present instruction in structural engineering. However, before taking this step the theory and practice of welding design must be thoroughly worked out.

Arc Welding in Bridge Construction

Actual examples of welded bridge construction are few, but the possibilities are many.(14)

Some test data of welded structural steel are already available,(15) together with a summary of them and an explanation of a method of designing a welded structural joint.(16)

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(13) "Arc Welded Steel Building," by A. G. Bissell, *Welding Engineer*, May, 1925, p. 17.

(14) Other examples of welded buildings are given in "Welding as a Method of Fabricating Large Structures," by H. Goldmark, W. Spraragen, and W. L. Warner, *Journal of the American Welding Society*, Oct. 1924, p. 27.

(15) "Arc Welding of Structural Steel," by E. S. Humphreys, *The Iron Age*, May 25, 1922, p. 1422.

(16) "Design of Welded Steel Truss for Static Loads," by Prof. F. P. McKibben, *Journal of the American Welding Society*, Oct. 1924, p. 56.

The most recent example of a successful arc-welding repair job on a bridge took place at Paris, France, the bridge being of arched construction and the material cast-iron.(17)

However, the riveting process as applied to bridge construction is very firmly established and riveting methods are thoroughly standardized. In order to make effective headway with the introduction of arc welding in bridge construction, efforts should be directed to obtaining much more test data of an authentic and conclusive character.

Unfired Pressure Vessels

Welding is entirely adequate for the construction of all kinds of pressure vessels. It is confidently expected that the present restrictions in the A.S.M.E. Code in regard to welding will be modified and made more liberal, based upon the scientific evidence now available and soon to be obtained by the Pressure Vessel Committee of the American Bureau of Welding. Tanks designed for 250 lb. pressure have withstood pressures as high as 2400 lb. before bursting. Welding can produce a better and cheaper tank than riveting when properly designed and constructed under approved technique and proper supervision. The test recommended by the American Bureau of Welding for pressure vessels is indicative of the confidence which may be placed in properly constructed vessels. This test calls for hammering a tank when under a hydrostatic pressure of 1½ times the working pressure, after which the pressure is to be raised to three times the working pressure and held there three minutes except in the case of vessels of special construction such as shell and tube brine coolers, condensers, intercoolers, etc., in which case the pressure shall be raised to two times the working pressure. This may be compared with the hydrostatic test of 1½ times the working pressure required by the A.S.M.E. Boiler Code for riveted vessels.(18)

Fired Pressure Vessels

Many types of steam and hot-water boilers and fired pressure vessels for various industrial purposes ranging from low pressure to high pressures and high temperatures are now in successful use.

As an illustration of what may be done by welding there is cited the gasoline cracking still manufactured by the A. O. Smith Corporation. This still is made of 2½-in. plates, is 41 ft. in length, 5 ft. inside diameter, is subjected to 500 lb. per sq. in. working pressure, temperature inside 950 deg. F., temperature of furnace 1500 deg. F. On test one of these stills withstood a hydrostatic pressure of 4700 lb. per sq. inch without affecting the welds. Of course, the manufacture of a product of this nature requires expert knowledge of welding including physical phenomena, materials, metallurgy, design, and heat effects on steel.

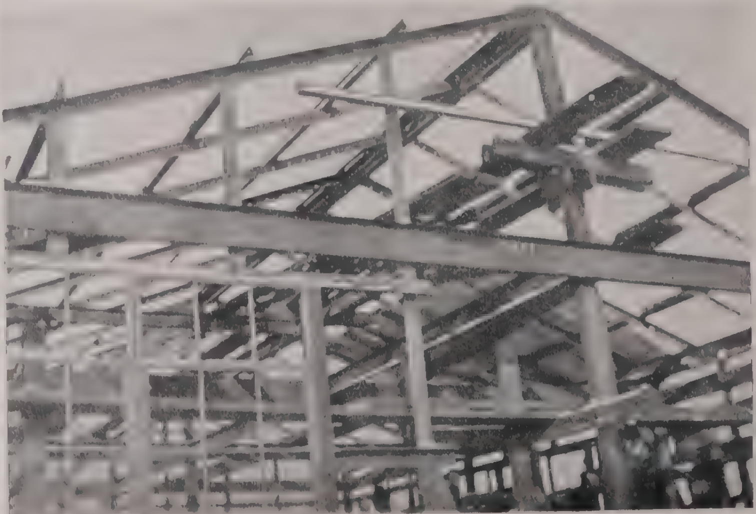
Fig. 1. Completely Arc Welded Building Erected by the Chicago, Burlington and Quincy R.R. for a Reclamation Plant at Eola, Ill. Scrap material was used, hence the rivet holes

Arc-welded Radio Towers

In 1921, two welded radio towers 150 ft. high, and largely of steel pipe, were built at Pekin, China. The welding was done entirely by unskilled Chinese labor. After gaining experience on the first tower, the second tower was completely assembled in position in seven days and completely welded in another seven days. The antenna occasions a horizontal pull of 3000 lb. The tower is designed on the basis of a wind load of 25 lb. per sq. ft. of projection in one plane.(19) There are several distinct advantages to be found in the design and construction of such towers. The members are round and offer relatively small resistance to wind. Pipe sections give nearly perfect columns, having the greatest strength possible for a given amount of metal. Short pipe ends are used up in the construction. Arc welding is much cheaper, quicker, and easier than riveting. The use of material of light weight permits easy erection of long shop sections. The finished tower has smooth lines and offers a pleasing appearance.

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(17) "Electric Welding for Bridge Repairing," by A. C. Blackall, *Welding Engineer*, Aug., 1925, p. 45.

(18) A $100,000 investigational program is to be undertaken shortly by the American Bureau of Welding. Those desiring to co-operate in this work should communicate with the secretary of the Bureau.

Electric Transmission Line Towers

Arc welding is particularly applicable to the construction of poles and masts of the lattice type for the support of electric transmission lines and radio aerials. About three years ago 500 transmission line posts of this type were constructed in Belgium. These posts are 72 ft. long overall, 5 ft. of this length being imbedded. They are built to carry two 3-phase lines and a guard wire, making altogether seven wires on spans of 525 ft. The stress due to the pull of the wires with a maximum wind blowing across the line is calculated to amount to 1350 lb. horizontal pull at the top of the posts. They weigh ten per cent less than those riveted in the usual way, and two welders can complete one of them in nine hours, using about 45 kw-hr. and 425 ft. of No. 10 electrodes.(20)

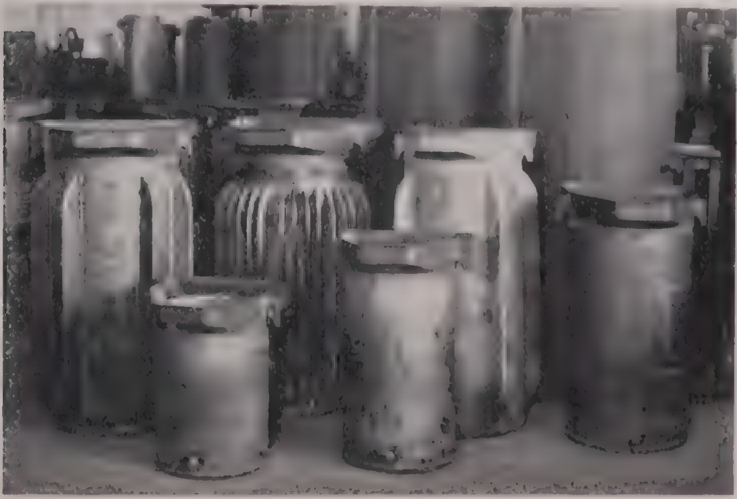

Fig. 2. Various Sizes of Arc Welded Tanks

One-hundred Foot Welded Tower

In a cave in California a 100-ft. tower was built up of spiral strips of steel inclosing a spiral stairway. Every joint of the 7200 in the structure was welded by the electric arc. The cost of the completed tower was $3000, as against the lowest estimate on a riveted structural steel tower of $12,000. The steel used in the welded tower weighed slightly over 3 tons. The weight of a similar structure bolted and riveted would be 13 tons. While not definitely known by the authors, they assume that the welded construction permitted the use of very much narrower strips for the entire structure as compared with riveting where a rivet hole constituted an appreciable part of the section of the strip.

Steel Flooring

An all-welded steel floor 64 by 24 ft. was constructed by the Hershey Chocolate Co., for its milk receiving room. Heretofore, cement and bituminous flooring were used with more or less leaking and a great tendency to crack. Three hundred thousand pounds of milk enter this room daily, mostly in 100-lb. cans. The plates were cut 4 by 10 ft. by 3/8 in., and planed to a 45-deg. bevel. The floor had to be 100 per cent waterproof and have as great a resistance to shock and abrasion as possible. This type of construction being smooth, it is possible to slide the cans over the surface, netting a saving of about $1200 annually on labor alone.

Impact Pulverizers

The Raymond Brothers Impact Pulverizer Co. of Chicago manufactures a system consisting of a grinding mill and pulverizer, an air separator exhaust fan, cyclone collector, a tubular dust collector, and the necessary connecting pipes. The construction of one of these mills necessitates the use of a wide range of thicknesses of sheet metal and a great variety of joint design. The tops for air separators, return air housings, fan housings, etc., are all welded. As a result of the applications of welding, the finished product is more economical and stands up better in service than riveted joints. Moreover, they are absolutely dust tight. A considerable saving is also effected in the designing room, particularly in the matter of drawings, which is a considerable part of the total cost of such a structure.

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(19) "Arc Welded Radio Towers," by H. S. Bear, *Welding Engineer*, Sept., 1922, p. 29.

(20) "Electric Arc Welding in Steel Structures," by Major James Caldwell, *Engineering*, Jan. 20, 1922, p. 88.

Stacks for Buildings

The Boom Boiler & Welding Co. produces both riveted and welded stacks. It states, however, that a rapidly increasing number of owners are demanding the welded product. Welded construction results in 100 per cent efficiency of joints in a stack as compared to 60 per cent for riveted construction. Breachings and gas and smoke conductors in a stack generally allow leakage when riveted, which spoils the vacuum, hence handicaps the draft. When these parts are welded, the joint is 100 per cent air tight. Joints of a stack that must be subjected to heat strains can be held tight when welded, where they will give if riveted. Moreover, a welded stack has no rivet heads or rough edges to collect soot and soft coal, which form sulphuric acid and eat into the stack.

Steel Flasks

So successful has been the application of arc welding to the building of steel flasks, specially formed shells used in making sand molds in foundries, that one of the largest producers of these has entirely discontinued the manufacturing of the cast or riveted product in favor of the welded steel flasks.

The arc-welded flasks afford decided advantages over other styles, engineers report. Because the electric welding makes the sections practically one piece, the flasks are given greater strength and rigidity. The welded steel products also eliminate all annoyance caused by pieces coming apart as is apt to be the case with bolted or riveted flasks.

The flasks are made in a wide range of sizes from the small bench-work styles up to the large, heavy-duty sizes. The lighter flasks are built of ⅛ and 3/16-in. steel, while the larger and heavier ones are made from ¼-, 5/16-, and ⅜-in. steel. The shells of welded steel construction are being made in practically any square or rectangular shapes. The cope or drag of the flasks ranges from 2½ to 18 in. in depth.

All-welded Steel Furnace

Welding also gives a leak-proof and strong union in the construction of steel furnaces.⁽²¹⁾

Locomotive Tender

A locomotive tender has been completely arc welded at the West Springfield shops of the Boston and Albany Railroad. The tender tank is 26 ft. long, 10 ft. wide, 5 ft. high, and has a capacity for 8000 gallons of water and 12 tons of coal. It is used with a Pacific type locomotive for passenger service.⁽²²⁾ Arc welding is satisfactory for this work, as it can be done economically and with strength of joints in excess of that usually obtained from riveted construction. Some 1200 ft. of welding are usually required on a tank of this sort.

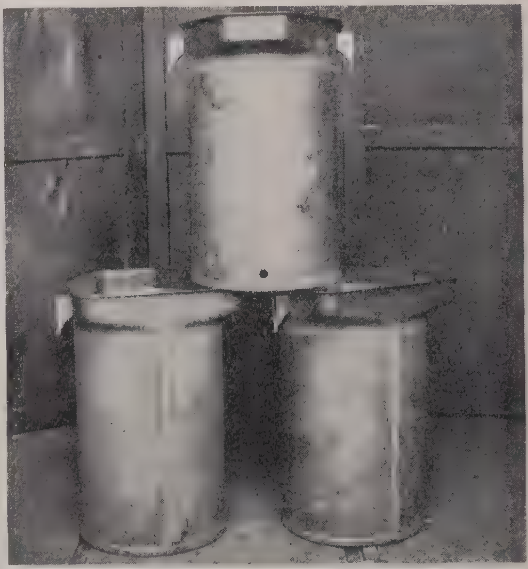

Fig. 3. Sheet Steel Transformer Tanks Welded with Automatic Arc Welder

Miscellaneous Applications

A very large number of rear-axle housings are now built by using the automatic arc-welding machines.

Water jackets may be formed economically of steel tubing and assembled by arc welding, using hand or automatic welding.

Radiator covers may be assembled very quickly and economically by welding light-gauge metal with either the metallic electrode operated by hand or by the automatic arc-welding machine.

Artistic baskets, guard rails, and lawn rollers have been welded on a production basis.

Silent chain drives are now enclosed in welded casings which keep out dust, retain oil, and increase safety.

Attractive medicine cabinets for bath rooms are now entirely constructed by weld-

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(21) "Production Welders Since 1898," *Welding Engineer*, June, 1925, p. 19.

(22) "Electric Arc Welding on Steam Locomotives," by W. M. B. Brady, GENERAL ELECTRIC REVIEW, Oct., 1924, p. 687.

ing, using oxy-acetylene, electric arc, and spot welding.

Ballast boxes are economically constructed by use of welding and are of a very rugged design.

A job welding shop in Oklahoma has proved that welding results in a stronger, neater, and more satisfactory job for greasing racks and tank supports, with a saving of approximately one-third on labor.

A sky scraper swimming pool was constructed on the twenty-first story of the Chicago Union League Club. Arc welding was used to insure absolute tightness.(23)

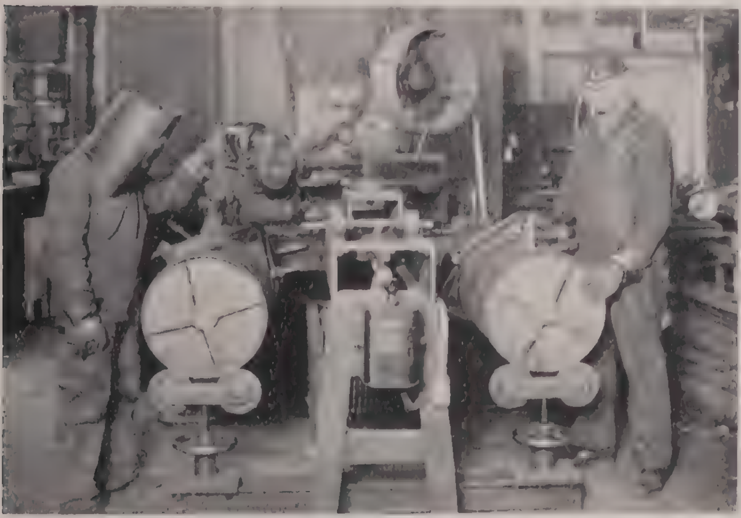

Fig. 4. Automatic Arc Welding of Sheet Steel Transformer Tanks. Assembly of tanks also shown. The machine has provision for preparation of work on one side by one man, while on the other side the machine is welding work already set up. This cycle is continuous

The Use of Arc Welding in the Factories of the General Electric Company(24)

Arc welding has been used at the several works of the General Electric Company for several years past with marked success. Its introduction has been responsible for a change in design of some of the lines of apparatus whereby the use of arc-welded boiler plate has been substituted in place of cast-iron. It is a matter of interest to note that in one of our factories, in 1913, we were using twelve arc welders on thin sheet steel (1/16 in. and 3/32 in.) transformer tanks. The seams were welded by means of the carbon arc, there being no metallic electrode welders employed at that time. Today the same factory is using 57 arc welders, 52 using metallic electrodes, and 5 carbon electrodes. Each month these 57 welders consume 13,500 lb. of welding wire, 1000 carbon pencils, and 40,000 kw-hr. of electrical energy. They do 67,500 ft. of welding, which works out at an average of 6.2 ft. per hr. for each welding operator. This includes much preparatory work. The speed when actually welding is of course much greater. The consumption of electricity averages 0.59 kw-hr. per ft. of weld. The consumption of welding wire works out at an average of just about 1 lb. per welding operator per hour. While actually engaged in welding, the consumption is of course at a considerably higher rate.

The following are the different lines of apparatus on which arc welding is being used:

Transformers

Arc welding is used for tanks, transformers, regulators, metering equipments, conservators, transformer breathing pipes, treating and dipping tanks, trucks, racks, and bushing adapters. From several years of experience in making oil-tight joints and seams such as are required on transformer work, we have found that arc welding is about 15 per cent cheaper than riveting. These figures are estimates based upon average conditions. In one of our factories where welding has replaced castings on the tops and bottoms of some transformers, a saving of about 25 per cent was made. Figs. 2, 3, and 4 relate to arc welded transformer tanks.

Locomotives

We are using arc welding for electric locomotive parts, and it has taken the place of riveting for battery boxes, cabs, gear cases, air compressor frames, air compressor crank shafts, controller frames, miscellaneous brackets, and cabs. Studs in split gears are secured by the carbon arc. By the use of heavy currents, deep penetration is secured. Gas welding cannot be used on this line of work due to the gears being heat treated. The average saving secured on this line of work is approximately 25 per cent.

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(23) "A Sky Scraper Swimming Pool," *Welding Engineer*, Sept., 1925, p. 17.

(24) The remainder of this article is quoted from a report by M. A. Atuesta, Chairman of the General Electric Company's inter-factory welding committee.

Electric Motor Frames

Automotive motor frames made of ⅝-in. steel plate rolled and welded by the automatic arc-welding machine have displaced the steel casting with a saving of $2 per frame.

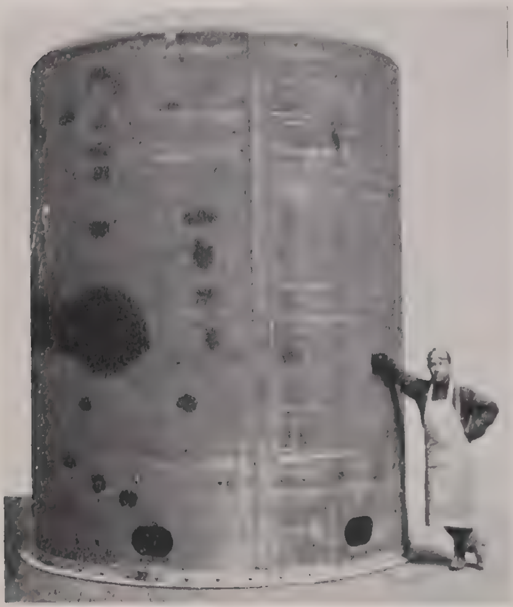

Fig. 5. A 220,000-volt Hand-welded Oil Circuit Breaker Tank

Pole-piece Assembly

Laminated pole pieces are welded after assembly to prevent their creeping when being drilled and tapped. We have found that this work can be done only with arc welding.

Commutator Shells

Commutator shells made of stamping steel are assembled by arc welding. Their weight is much less than the cast shell and no machine work is required.

Motor Bases

Bases for motors and motor-generator sets are made of channel iron and I-beams, arc welded together. The outstanding feature of these bases is light weight, combined with strength and quick assembly. They have replaced the cast-iron base. The saving obtained on this kind of work has been 25 per cent.

Motor Fields

Induction-motor field punchings are pressed into a seamless steel tube and the end-rings are welded, which does away with rivets through the punchings. While no particular economy in manufacture has been effected, this method results in a better field because the increased compactness does away with loose laminations.

Terminal Boards

Terminal boards for motors which are arranged for armored conduit connections are assembled by arc welding because of the high speed of this operation.

Generator Stator Frames

Generator stator frames which were made from castings are now fabricated from steel plate and arc welded. The saving from this change is considerable.

Oil Pans

Oil pans for vertical waterwheel-driven alternators which were made by riveting and soldering to obtain leak-proof joints are now arc welded, and complaints from leaky joints have ceased.

Oil Circuit Breakers

Oil switch tanks originally made by gas welding were changed to arc welding several years ago and a saving of 20 per cent was effected. After the automatic welding process was introduced for these tanks, an additional 15 per cent saving was effected, making a total saving of 35 per cent as a result of changing from gas to automatic arc welding.

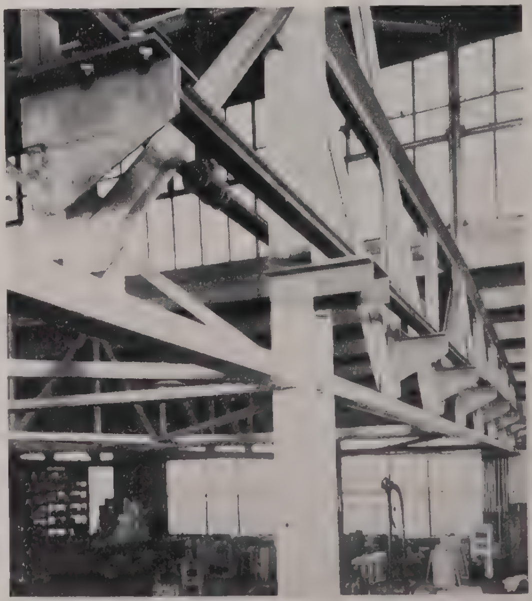

Fig. 6. Crane Runway Attached by Arc Welding

Fig. 5 shows a 220,000-volt hand-welded oil circuit breaker tank. Since introducing arc welding in the construction of oil circuit breakers, steel frame-work, sheet-steel solenoid housings, galvanized frame-work, and rotary auxiliary switches are being welded. Supporting pipes for switchboard panels and footplates for fastening them to the floor were formerly tapped and threaded. These are now being arc welded and show a saving of two to three cents each, more than 100,000 being used in a year.

Miscellaneous Tanks

Tanks of various descriptions used in the factory, such as oil, water, water rheostat, and ship regulator tanks, all of which were formerly in most cases riveted, are now being welded and show a saving of approximately 25 per cent.

Miscellaneous Structural Iron

Fabricated frames for truck panels are mostly arc welded. The exact saving is not obtainable. We are also arc welding a quantity of structural steel work in several of our factories, the saving in many instances showing at least 15 per cent. Fig. 6 shows the use of arc welding in attaching a crane runway to the steel framework of a factory building.

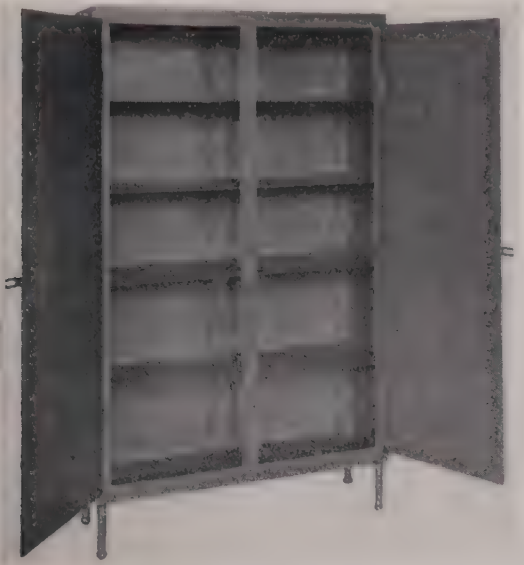

Fig. 7. All Electric Welded Cabinet

Castings

Large steel castings defective in some respect are now being saved and made usable by the use of arc welding. We are unable to estimate the saving effected in this line of work owing to the fact that prior to the use of arc welding many of these castings were rejected and had to be replaced by new castings, there being times when the defects were not discovered until machining operations had been started. All of this trouble has been eliminated by arc welding.

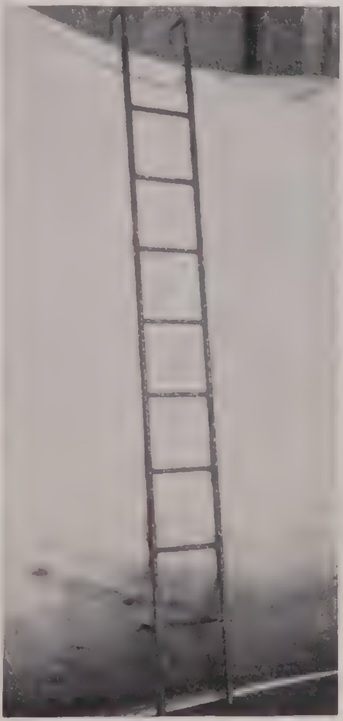

Fig. 8. Steel Shop Ladder Made of Steel Pipe by Arc Welding

Miscellaneous Shop Equipment

Steel racks, lockers, cabinets, and shelves are now being welded showing a saving as high as 40 per cent. Fig. 7 shows an arc-welded cabinet. Fig. 8 shows a welded-steel shop ladder, and Fig. 9 some welded stools.

Furnaces

Furnaces of different descriptions that were previously riveted are now in most cases being electrically welded.

Mercury Boiler

Mercury boilers, turbines, condensers, and accessories are practically all electrically welded. It is difficult to estimate the amount of money saved by welding, but we feel reasonably sure that without the use of arc welding we would be unable to make some of this equipment leakproof. This was shown in the early stages of the manufacture of the mercury boiler when some of the equipment was riveted and it was found later that it was necessary to weld these parts in order to make them leakproof. Fig. 12 shows the arc-welded shell in which the mercury vapor is condensed.

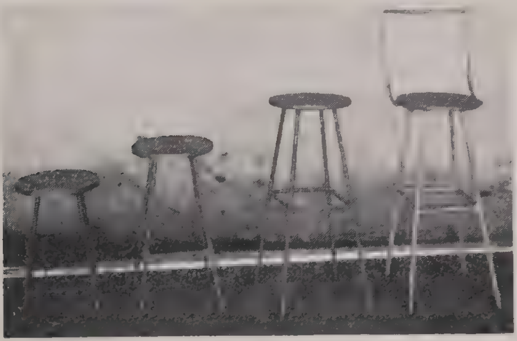

Fig. 9. Steel Shop Stools Made of ⅜-in. Pipe by Arc Welding

Arc Lamps

Guide tubes for arc lamps, consisting of a steel tube and malleable iron support, are now arc welded. Considerable time and money has been saved by this change from gas welding.

Rectifiers

Armatures for mechanical rectifiers are now being assembled with the use of arc welding, due to the fact that the weight of the component parts must be the same before and after assembly. It is of interest to note that these parts are welded with an electrode about 1/32 in. in diameter, using a current of 8 amp.

Compressors

The chief advantage in welding compressor castings lies in the fact that welding makes flexibility of design readily possible. For this purpose only the arc can be used.

High-pressure Oil Pipes for Turbines

Flanges for holding pipes together were originally threaded to the pipe and in some instances welded with gas. By making a slight machine change in the piping and flange, an oil-tight joint can now be made by welding with the arc. Fig. 11 shows a welded strainer for a steam supply line for a high-speed turbine. The screen material is monel metal.

Building Up Shafts

A great many armature shafts used throughout the factory which have become worn at the journal or at the coupling or pulley fit are now being welded without stripping the armature, thereby causing an immense saving which is rather difficult to estimate.

In many cases a complete armature is reclaimed by merely building up the shaft. The work has been done by automatic means.

Copper-hydrogen Brazing Furnaces

The copper-hydrogen brazing furnaces used in our factories are now being arc welded, primarily to prevent the leakage of hydrogen gas. We are also tack welding the several parts to hold them together before they are placed in the brazing furnace.

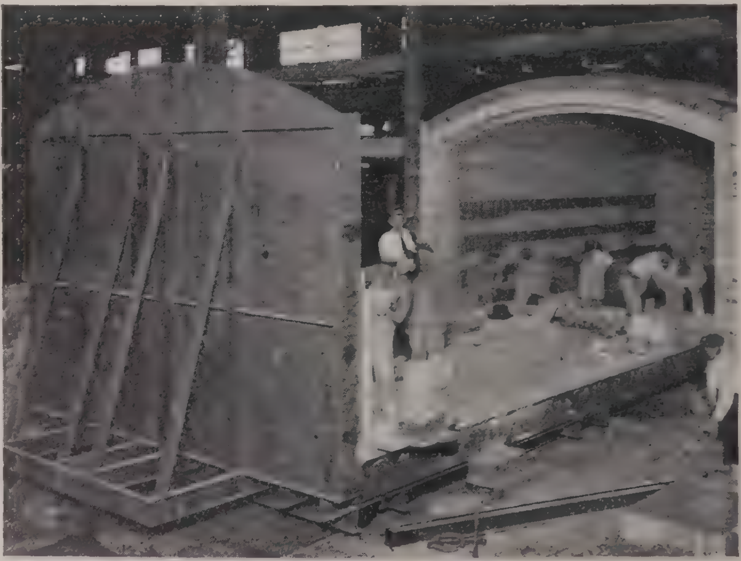

Fig. 10. A Large Annealing Cart Completely Electric Welded

Wire Enameling Machines

By arc welding, wire enameling machine jackets can be assembled in the towers in about one-half the time that was formerly required.

Flow-meter Nozzles

The construction of flow-meter nozzles when made of steel is such that it is impossible to form them in a die without splitting the flange. This has been overcome by making them in two parts and automatically welding the parts together.

Jigs and Fixtures

Jigs and fixtures are cut and assembled by arc welding. This does away with an expensive pattern which is used only once. Many times the completed jig costs less than the pattern itself. One important saving in this line of work is time.

Miscellaneous

Flash backs, manifolds, various pipe connections, and Nichrome ribbon used for resistors in heating units, are now being arc welded due to the ease with which the parts can be assembled. Other parts which are being arc welded and upon which we are unable to ascertain the amount of saving are such as: truck floors, racks, bearing brackets, broken gears, leaky locomotive boiler tubes, broken automotive frames, steel plates for molding insulation, and armature spiders.

Conclusion

As a general observation gained from our experience in the making of tight joints and seams, such as are required in much of our work, we have found that arc welding is about 15 per cent cheaper than riveting.

In the welding of thin sheets up to 1/16 in. the cost of gas welding is no higher than arc welding, while for thicknesses greater than 1/16 in. arc welding is cheaper.

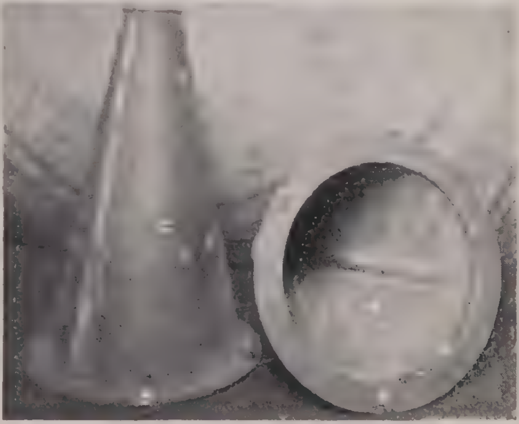

Fig. 11. Strainers for Turbine Steam Lines. The inside screen (*A*) is of monel metal and the outside screen (*C*) is of steel

Satisfactory oil-tight seams cannot be made in steel much thinner than ⅛ in. by riveting. Riveted seams in this thin steel are usually soldered or a gasket is employed to guarantee a tight joint. With the electric arc this is not necessary.

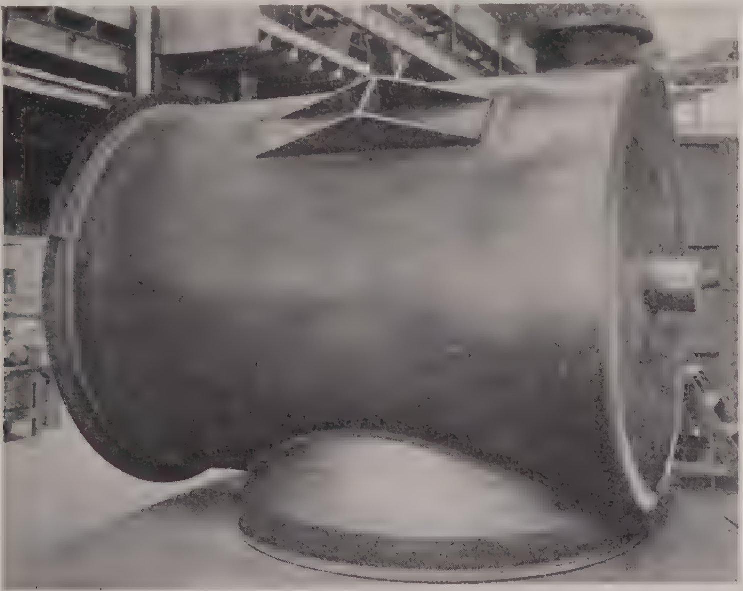

Fig. 12. Special Condenser Boiler Shell. All seams electric arc welded

Electricity in the Manufacture of Ice

By D. W. McLenegan

Industrial Engineering Department, General Electric Company

Heat naturally flows in the direction of lower temperature and can be made to flow into a region of higher temperature only by applying an ingeniously arranged series of Nature's laws together with a supply of mechanical energy—which paradoxically is equivalent to expending heat energy in order to get rid of heat. Having once accepted this, there are theoretically several methods of energy supply which can be adapted to the production of refrigerating temperatures. Steam power, water power, and oil engine power have been successfully employed for this purpose. Theory alone, however, does not tell us the most practicable and inexpensive way to make ice. It has taken years of experience and a constantly increasing pressure of competition and the limitations of space to demonstrate that electricity in ice manufacture can attain economies and reliabilities impossible with any other form of power supply. The present article gives a complete picture of a block of ice made by electricity.—Editor.

General Advantages of Electric Drive

Within the last few years the manufacture of raw water ice by artificial means has become so extensive that in the larger cities manufactured ice has practically supplanted natural ice for domestic use. Accurate data are not available on the present extent of the manufactured ice industry, because the production has increased so rapidly since the last census (1920), due to the application of electric drive to ammonia compressors. Manufactured ice has a great advantage over natural ice in large cities, where the quantity required is so great that it is impracticable to harvest all of the latter in the winter and provide storage capacity to carry it through the summer. However, many ice plants provide storage capacity for about one month's output, as this capacity will absorb the production during the early season, as well as reduce the demand on the ice making machinery during the summer.

Nearly all of the ice plants which are being installed at present employ electric drive for the main units and the auxiliaries. In addition, many steam-driven plants are being converted to electric drive. The changeover from steam engines to electric drive for the compressors has been due largely to the increased economy of operation and the saving in space which the electric plant permits. By using central station power, the ice plant operator eliminates his own boiler plant, engine, and the necessity of having a coal storage space and a means of ash removal. The expense of firemen and boiler room attendants is also obviated. In some of the metropolitan districts, the power companies make special arrangements to insure reliable service to the ice plants. In New York, for example, a group of large ice plants is served by a special high-tension circuit which carries no other load.

Diesel engines also have been advocated for driving ammonia compressors, but comparatively few installations of this type have been made, the majority being steam engine or electric motor drives.

The main requirements of an ice plant power system are that it should be reliable and flexible. Since most of the profit in the ice business is made during the few summer months there must be no interruption of production during this time due to trouble with the machinery. Ice plants are being designed with this point in view and duplicate equipment is frequently found on such apparatus as cooling water pumps, brine circulating pumps and agitation air compressors. Excess capacity is often provided in the transformers. As regards flexibility, where several compressors are installed, the operator can shut down one or more and the electrical equipment will still operate at full-load efficiency. In a steam plant this is impossible because some of the boilers must be taken out of service or run at reduced capacity, which gives poor economy. However, although economy and efficiency of the apparatus are of great importance, the equipment selected must primarily insure the operator of continuous service during the busy season.

Another advantage which has furthered the application of electric drive in ice plants is the relative ease with which the electrical equipment may be located to suit the space requirements of a plant. Except for such items as floor strength and the cost of feeder cables, the ice plant layout may be made practically without considering the effect of the location on the electrical apparatus. The motors and compressors may be located in the upper section of the plant, if this is found desirable, whereas engine drive requires the compressor to be down near the

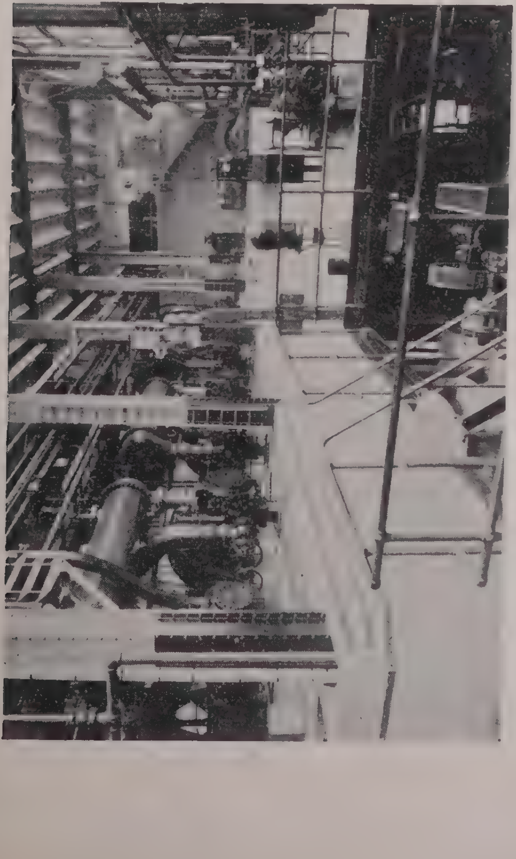

Fig. 1. General View of Engine Room, Arctic Hygeia Ice Mfg. Co., New York City

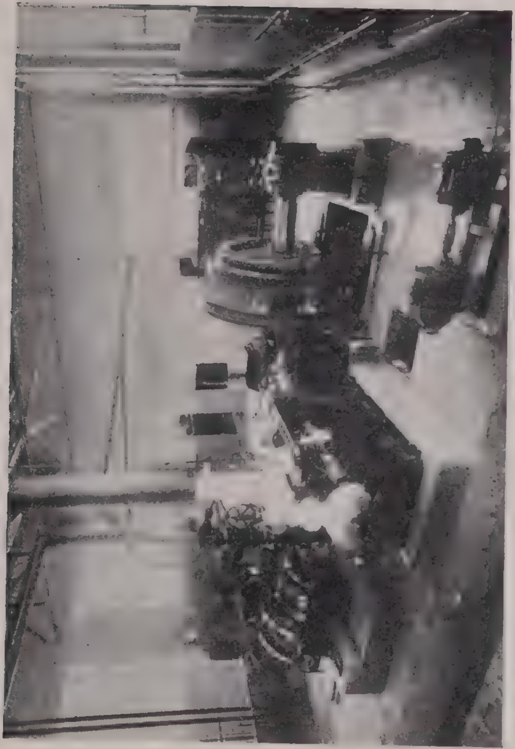

Fig. 2. A Typical Compressor Room, Showing Motor-driven Ammonia Machine and Electrical Auxiliaries

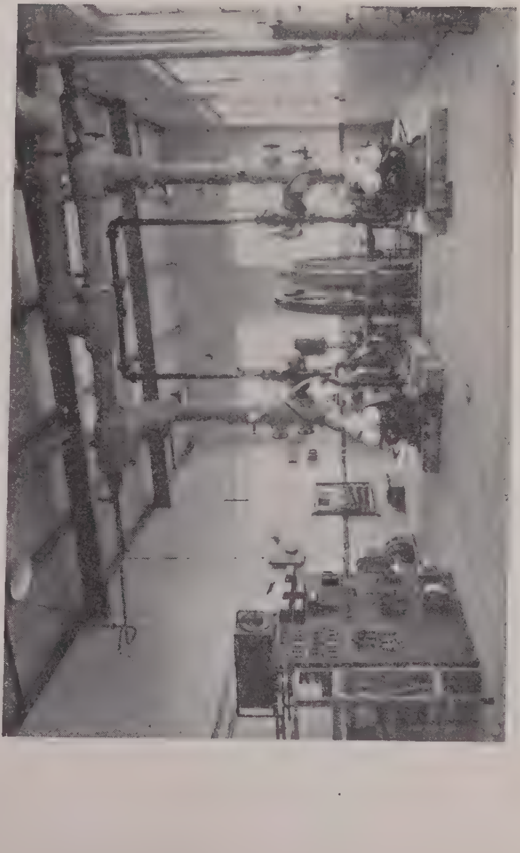

Fig. 3. 350-h.p. Synchronous Motor and Flywheel Connected to Compressor, Diamond Ice & Coal Co., Charleston, W. Va.

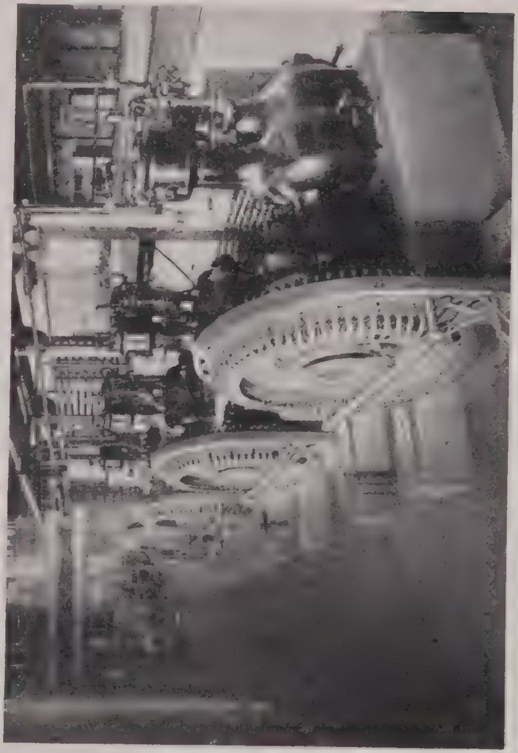

Fig. 4. Group of Ammonia Compressors in the Detroit Ice Corp. Plant Driven by 3-phase Synchronous Motors

boiler in all cases. Transformers may be housed adjacent to the compressor room, or located on the roof. If the plant is built on valuable land, or has to be fitted into a certain space, this adaptability of electric drive is a considerable advantage, since the plant may be laid out to suit the needs of the refrigerating system, unhampered by considerations affecting the drive of the main units and the auxiliaries.

Several representative installations of electric drive in ice plants are shown in Figs. 1 to 4.

Process of Ice Manufacture

The operation of an ice plant will first be briefly outlined, starting with the finished product and tracing backward the steps of the process by which it is made. Following this, detailed consideration will be given to the different types of machines employed in the sequence of manufacture, together with the electrical apparatus for their drive. Fig. 5 is included as a schematic diagram of the equipment.

The ice cake is formed in galvanized cans previously filled with water which during the process gradually freezes from the sides of the cans inward, until a solid mass is produced. Refrigeration results from these containers being three-quarters submerged in a large tank of brine maintained at a temperature below the freezing point of water.

The brine itself must be kept cool by a still colder medium, the ammonia. Cooling coils containing ammonia gas at low pressure (15 to 20 pounds gauge) are located in the brine tank, and since the ammonia is only partially vaporized, it can absorb heat from the brine without an increase in its own temperature, which is from zero to 5 deg. F.

The heat which has been passed along from the fresh water to the brine and then to the ammonia must finally be taken out of the ammonia also and the method of doing this is the same in nearly all ice plants. After passing through the brine tank, the ammonia gas is drawn into the compressor and raised to a pressure which varies from 150 to 225 lb. per sq. in., depending on the design of the plant and local operating conditions. Its temperature will then be 85 to 110 deg.

The high pressure ammonia gas from the compressor passes through the tubes of a condenser, where ordinary city water flowing around the tubes may be used to carry away the internal heat of the gas and condense it to liquid form. From the condenser, the ammonia liquid flows into a small reservoir and is then allowed to expand through a reducing valve to a pressure of 15 to 20 lb. per sq. in. above atmospheric pressure. In expanding, the liquid becomes partially vaporized, and its temperature drops to the low value, 0 to 5 deg. F. In this condition, the vapor is piped to the cooling coils in the brine tank, where it accomplishes the cooling of the brine.

To sum up, then, the ammonia gas absorbs heat at about 5 deg. F., in the brine tank, and gives up heat at about 95 deg. in the condenser. The compressor, therefore, has served merely as a heat pump or "elevator" to permit the removal at high temperature of the same energy which was added to the gas at low temperature.

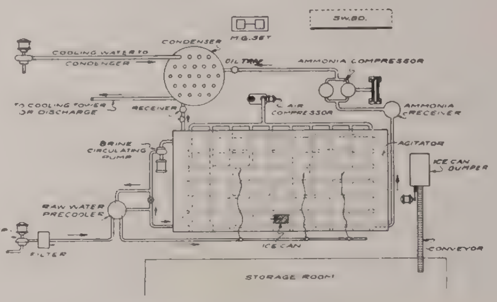

Fig. 5. Diagrammatic Layout of Equipment in a Typical Ice Plant

To raise the ammonia gas from its low level of 5 deg. and 15 lb. pressure to the high level of 95 deg. and 185 lb., work must be done. This work is supplied by the electric motor driving the compressor. Also, the circulation of the brine in the ice tank and the cooling water in the condenser must be maintained by external means, and motor-driven pumps, with their electrical control, must be provided. If the power supply is at a voltage too high for the motors, transformers must be provided to reduce the voltage to a value best suited to the motor requirements.

Plant Equipment

To describe the equipment of a typical ice plant, the foregoing outline must be modified to include a description of the many auxiliary devices, as well as the characteristics of the main units. To correspond with the outline, the equipment will be described in the same sequence, as nearly as possible.

Ice Cans and Brine Tanks

Certain features of construction are common to nearly all raw water ice plants. Galvanized iron cans in which the water is frozen are of dimensions approximately 10 in. by 20 in. by 48 in. in height. These cans are placed vertically in the brine tank and filled to a level which yields a 300-lb. cake of ice. The number of cans in a single brine tank varies with the design of the plant and may be as high as a thousand. The space between adjacent cans is very small, usually three or four inches, and the ammonia piping extends between these cans to cool the brine. In other systems, the piping is located only between two brine tanks and the brine is circulated around the piping and then through the tank. There is sometimes a vertical partition running down the middle of the tank. The brine is kept in circulation around the ammonia pipes and around the ice cans by means of centrifugal pumps located adjacent to the tank and driven by squirrel-cage motors. In addition to these, two or three vertical propellers, each driven by a 3-h.p., 900-r.p.m. vertical induction motor, Fig. 6, are used to keep the brine in motion in the corners of the tank where the circulation would otherwise be poor.

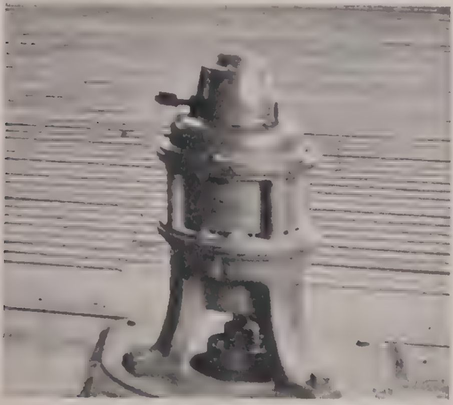

Fig. 6. Vertical Agitator Motor Installed Above Brine Tank

Where removable ice cans are used the general practice is to lift from one to six cans of ice out of the brine at one time and convey them by an electric crane over to the end of the ice floor where there is generally a tank full of warm water which serves to loosen the ice cakes from the ice cans. This water comes from the jacket of the compressor or is taken from the circulating water which has flowed through the condenser.

Air Agitation

If clear transparent ice is to be obtained, it is necessary to keep the water in the cans in motion while the freezing occurs. The freezing begins at the edge of the cans and progresses towards the center. If the water in the can is kept in circulation by air bubbling through it, the impurities will be gathered into a small core in the center. Before the ice cake is completely frozen, these impurities, together with the remaining water, are drawn out either by a suction tube inserted into the ice can or by a drain in the bottom of the can, where stationary cans are used. With removable ice cans, a core suction pump must be used for drawing off the water and the impurities. This is driven by a squirrel-cage motor of 1 to 3 h.p., 900 to 1200 r.p.m., geared to the pump.

Air for agitating the water enters through a small tube which reaches nearly to the bottom of the ice can, so that the air can bubble up through the water. Various arrangements of the air pipe are used by different manufacturers. In one type of construction the pipe is solidly connected to one side of the ice can. In other systems, the pipe is frozen into the cake of ice, and later removed by thawing with hot water. Two systems of air agitation for the ice cans are in general use. Some manufacturers of ice machinery recommend a pressure as high as 20 pounds, while others use low pressure systems which operate on 5 or 3 pounds pressure.

Air Compressors

High-pressure agitation air is generally supplied by a small reciprocating air compressor of the single-cylinder, double-acting type, running at a speed of 240 to 360 r.p.m. The general practice has been to drive this compressor by a belted squirrel-cage motor running at 900 r.p.m. Many large plants, however, have used direct-connected synchronous motors for agitation service where an air compressor of 40 h.p. or more was required. Such an installation is shown in Fig. 7.

Synchronous motors of 20 h.p. and higher are now coming into use for this service, since they can easily be overhung on the shafts of the compressors. With speeds of 240 to 360 r.p.m., the flywheel requirements are easily met, and a considerable saving in space may be made over that required by belted units.

A few plants having high-pressure agitation systems use a positive pressure blower instead of the reciprocating compressor. Such blowers are commonly driven by direct-connected squirrel-cage or belted motors running at 600 r.p.m. or more. The amount of agitation air required with a high-pressure system varies from 0.25 to 0.5 cu. ft. per min. for each 300-lb. can. The lower figure is probably adequate in nearly all cases.

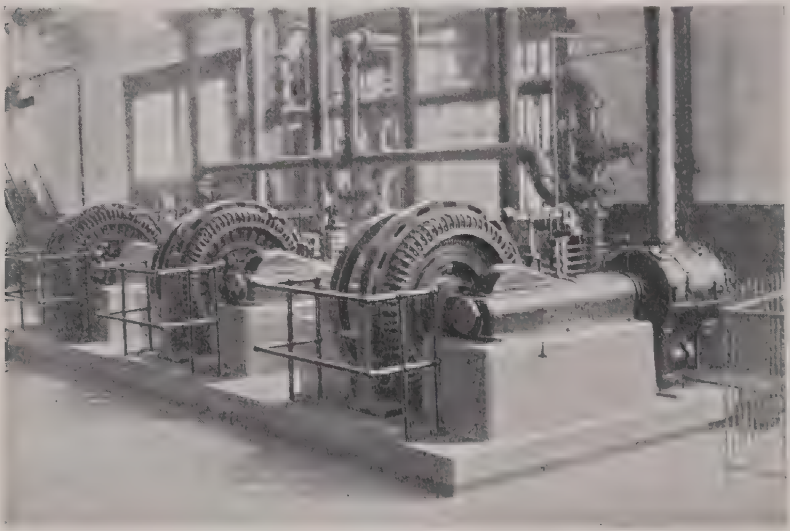

Fig. 7. Compressors and Motors of the Arctic Hygeia Ice Co.

Dehydrator

With high-pressure agitation systems, it is necessary to have a dehydrator for the air. After compression, the air is high in humidity. If it were allowed to go directly to the ice can, the moisture would condense and would very soon freeze up the agitation tube which is only ¼ in. in diameter. The air supply would then be cut off, and the ice would become clouded and would also freeze up the impurities which are ordinarily drained off.

Low-pressure Agitation System

In low-pressure agitation systems which admit the air from the top of the ice cans through a pipe similar to a high-pressure agitation pipe, a pressure of 5 or 6 lb. per sq. in. is generally used. This is a higher pressure than an ordinary centrifugal blower will furnish, but is easily obtained with a positive pressure blower driven by a direct-connected or belted induction motor

The freezing systems which admit air at the bottom of the ice can operate successfully on 3 lb. pressure which permits the use of a small centrifugal blower for agitation air supply. Such compressors are furnished with a direct-connected, 3600-r.p.m. squirrel-cage motor carried on the casing, so that an additional foundation for the motor is not required. A unit of this type is illustrated in Fig. 8. This system uses a larger pipe, of approximately ½-in. diameter, so that if the air pressure fails for a short time, the pipe will not become clogged up or freeze over, and the agitation can be resumed as soon as the air pressure is supplied again. The high-pressure system on the other hand relies on being able to force out of the pipe any obstruction which may have formed, provided the pipe is not entirely frozen over.

Air Storage Tanks

Some of the smaller plants have an air storage tank which takes the place of a standby air compressor. One 90-ton plant, for example, has a storage tank which will supply agitation air to the plant for half an hour. This tank is pumped up to 225 lb. pressure by means of a small motor-driven reciprocating compressor which

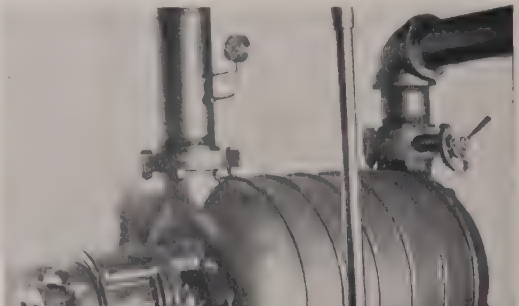

Fig. 8. 6-h.p. Induction Motor-driven Compressor Delivering 250 cu. ft. of Agitating Air Per Min., at 3¼ lb. per sq. in.

requires several hours to pump up the tank. The compressor is driven by a 2-h.p. motor. A reducing valve is supplied for reducing the air pressure to a usable value of 15 lb. However, in the larger plants it would not be practicable to install a tank of sufficient capacity to give an air supply for any length of time and therefore a standby compressor is frequently installed.

Brine Pump

The brine circulating pumps have already been mentioned. It is important to secure only a moderate circulation of the brine because if the flow is too great it will actually raise the brine level in one end of the tank and lower it at the other. In this case the rate of freezing will not be uniform throughout the tank. Squirrel-cage motors running at 1200 or 1800 r.p.m. are almost universally used to drive centrifugal pumps for this service, Fig. 9 showing an instance of such application.

Ammonia Compressor Motor

For driving the ammonia compressor, the arrangement generally recommended is a low-speed synchronous motor with rotor mounted directly on the compressor shaft. Most of the installations at the present time are being made with this arrangement, Fig. 10, except where space limitations prevent the use of a direct-connected motor with the additional flywheel which is necessary in some cases.

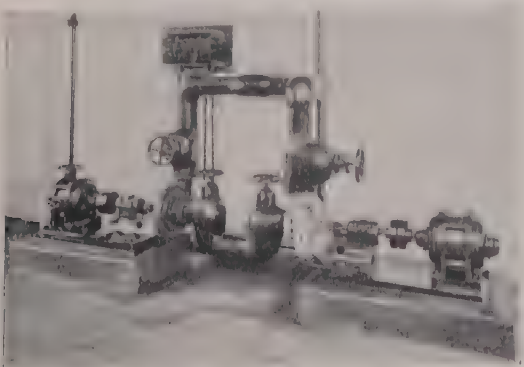

Fig. 9. Tandem Installation of Motor-driven Brine Pumps

Motors of this type are built in a wide range of sizes, from 20 to 800 h.p. or higher, and the large number of synchronous speeds within the ammonia compressor range (72 to 300 r.p.m.) makes it possible to choose a motor well suited to drive nearly any standard type of compressor. In spite of the comparatively low speeds required, the direct-connected synchronous motor in small sizes has an efficiency practically equal to that of a belted induction motor, and in larger sizes a better efficiency is obtained. The kilowatts of direct-current excitation required vary from about 5 per cent of the motor input, on some of the smaller machines, to about 1 per cent on large motors. The low speeds also make it possible to design motors having low starting currents, and in consequence, the practice of starting compressor motors on full voltage is rapidly increasing.

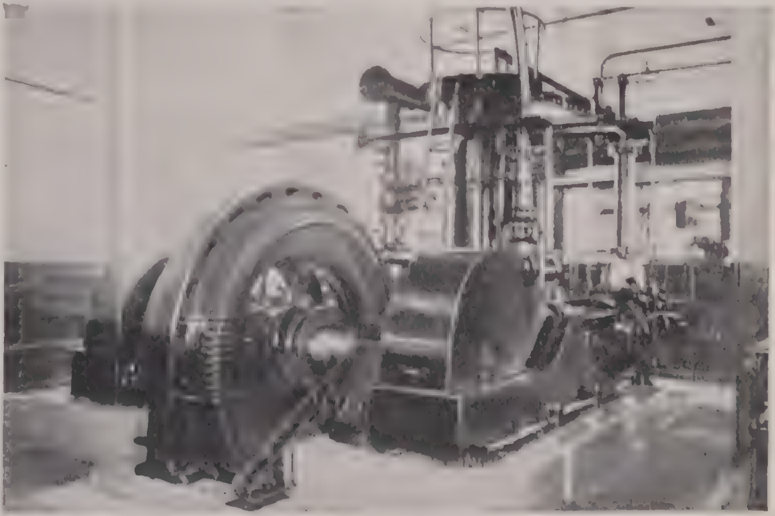

Fig. 10. 750-h.p. Synchronous Motor Driving Compressor at the Los Angeles Ice and Cold Storage Company's Plant

Due to its characteristic constant speed, a synchronous motor direct-connected to a compressor will draw a load current depending on the momentary variations in the torque required by the compressor. The problem of choosing the correct amount of flywheel effect for compressor drives has been investigated in great detail,(1) (2) since the torque pulsations must be limited to a value which will not injure the motor, nor cause serious fluctuations in the line current. It is now possible to predict within a few per cent the variation in current which will result with any given combination of compressor, motor, and flywheel, and arrangements can be made to incorporate the necessary amount of flywheel effect (WR^2) in the rotor of the motor or in a separate flywheel before the compressor is installed.

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(1) "A Short Method of Calculating Flywheels," by A. R. Stevenson, Jr., GENERAL ELECTRIC REVIEW, October and November, 1925.

(2) "Flywheel Requirements for Unbalanced Air and Ammonia Compressors," by C. W. Cutler, *Refrigerating Engineering*, September, 1925.

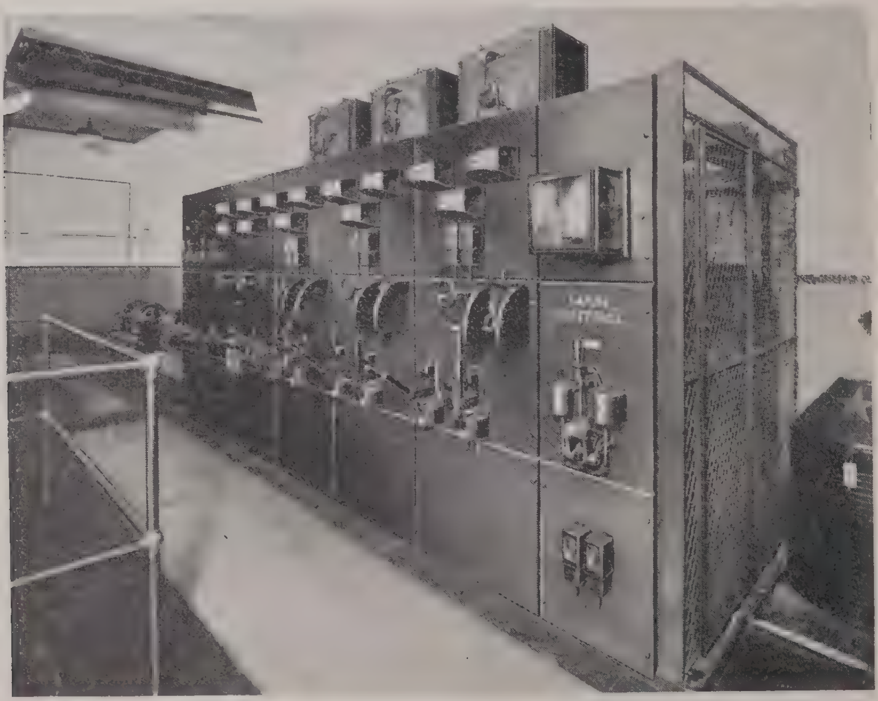
Fig. 11. Seven-panel Switchboard for Controlling 1600 h.p.

The stator of the synchronous motor rests on sole plates extending parallel to the compressor shaft. To allow easy access both to the rotor and stator, the sole plates are made long enough to permit movement of the stator sufficient to expose the rotor completely.

A smaller number of installations make use of a high-speed belted synchronous or induction motor, furnished with a base, shaft and either two or three bearings. For applications of this class, the belted synchronous motor, at unity or leading power-factor, is generally the most desirable, since it has the advantage of high efficiency, and also starting and synchronizing torques equal to the starting and running torques of an induction motor, in addition to the advantage of unity or leading power-factor. In motorizing old steam-driven compressors, the belted motor is frequently the best alternative, since compressors of this class usually operate at speeds of 70 to 100 r.p.m. and space limitations sometimes prevent the installation of a direct-connected synchronous motor with suitable flywheel effect. The advantage in first cost is in favor of belt drive. In some extreme cases, the slip-ring motor must be chosen because of the excessive starting duty involved in accelerating the heavy flywheels of these old machines.

There are also several successful installations of slip-ring motors connected to compressors through reducing gears or by chain drive and a few installations of synchronous motors with chain drive. However, since the synchronous motor cannot slip more than a few degrees with the variations in load, the flywheel effect must be carefully considered, and the chain must be of adequate size to avoid excessive strain and eventual breakdown.

Since the ammonia compressor motors usually constitute more than 65 per cent of the ice plant load, and since the induction motors driving the auxiliaries run at high speeds with fairly good power-factor, the power-factor of the plant will be near unity without requiring a leading power factor on the compressor motors. In a majority of ice plant installations, the compressor motors are designed for unity power-factor operation, although leading power-factor motors of the same horse power and speed are available. These motors, however, are larger and more expensive, and the additional investment is not considered to be justified in most cases.

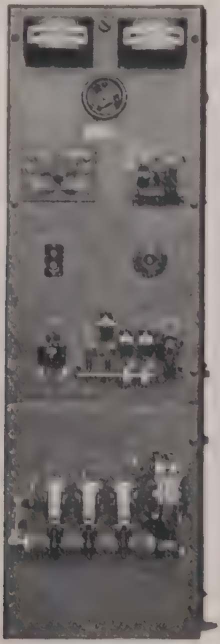

Fig. 12. Automatic Starting Panel for Synchronous Motor

Control

In the larger plants, the compressor motor panels and exciter panels are generally lined up with the incoming panel and the distribution panels, Fig. 11, so that all of the main control for the plant is centered in one place.

The distribution panel, which often serves also as a metering panel, includes an oil circuit breaker of sufficient capacity to safeguard the plant in case of a short circuit. In plants operating from a high-tension line of large capacity, this point is of particular importance. The metering equipment may include a recording or a graphic watthour meter, a power-factor indicator, maximum-demand meter, or a recording voltmeter, depending on the extent to which the operating engineer desires to analyze the operation of the plant.

If high-voltage motors are used for driving the compressors a transformer panel with a suitable circuit breaker may be provided ahead of the step-down transformers used for supplying low-voltage power to the auxiliary motors of the plant. A low-voltage distribution panel is usually employed, having knife switches to control the lines to the various auxiliaries, as well as the lighting circuits.

Several types of synchronous motor panels are in general use for controlling the main units. Since most of the compressor motors of a few years ago were belted induction motors, manually-operated reduced-voltage starters have probably been most frequently used. However, with the increasing use of synchronous motors, the automatic starter, with push-button control, has been widely applied. This starter, Fig. 12, carries out the starting operations without variation and provides additional safeguards which it is difficult to incorporate in a hand-operated panel. The full-voltage automatic starter, by which the motor is thrown directly on the line, has followed the development of synchronous motors having low inrush currents at starting, and its use is increasing rapidly wherever the supply circuit is of sufficient capacity to withstand the momentary load. "Across the line" starters have the advantage of simplicity and cheapness, and the application of full voltage brings the motor up to speed quickly and without hesitation, cutting down the duration of the starting inrush.

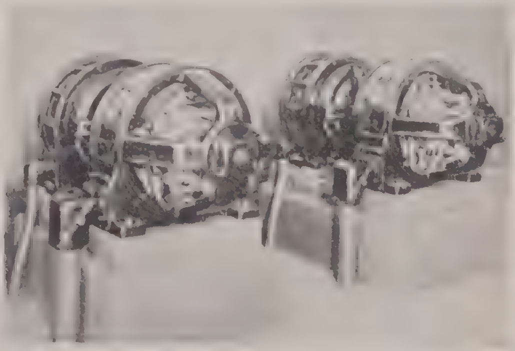

Fig. 13. Motor-generator Exciter Sets, Huffel Ice Plant, New York City

Exciters

Where several synchronous motors are installed, a single motor-generator set for excitation is usually employed, with a duplicate set as a spare, as in Fig. 13. A double-circuit exciter panel then forms part of the switchboard, so that the exciters may be paralleled, and the load shifted from one to the other without interrupting the operation of the synchronous motors.

For isolated motors, or motors operating intermittently, individual belted exciters or motor-generator sets are used, no control being used with the belted exciter. If the synchronous motor operates on low voltage and is started on full voltage, the motor driving the exciter may be connected across the synchronous motor terminals, and started simultaneously with the main motor. Due to its small inertia, the set will reach full speed and the exciter voltage will build up in time to furnish excitation for synchronizing the motor.

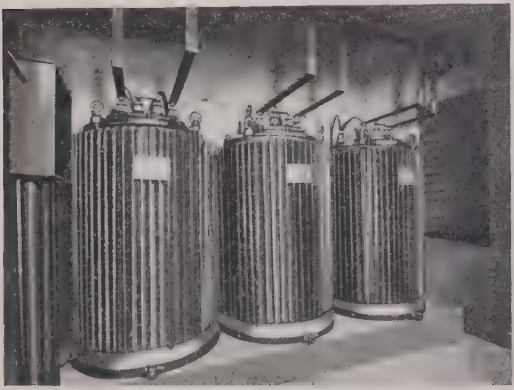

Fig. 14. Bank of Oil-cooled Transformers Typical of Ice Plant Installations

Transformers

Where a large block of power sufficient for the plant is available at a moderate voltage, up to 2300 volts, the compressor motors are designed for this voltage and the transformers are used only for supplying power to the auxiliary motors of the plant generally at 220 or, at most, 550 volts. But many ice plants which use a large amount of power are served by high-voltage lines at 4150, 6600, 7800 or 13,200 volts. Although 4150- or 4600-volt motors are frequently used, transformers are generally used at the higher voltages, since a lower voltage permits the design of motors of greater reliability and better operating characteristics.

Where the initial expense is not prohibitive, it is good practice to install three single-phase transformers of such a rating that, in case of failure of one transformer, the remaining two operating in open delta connection could carry enough of the plant load to give uninterrupted operation. Fig. 14 shows an installation of this kind. Since two single-phase transformers operating in open delta can carry only 58 per cent of the load which would be carried by three single-phase transformers of the same rating, this arrangement requires the use of oversize transformers. As an alternative arrangement, transformers of normal rating are sometimes used with an additional single-phase transformer as a spare. If the incoming voltage is above 550, a set of single-phase transformers or one polyphase transformer is installed to supply the auxiliary motors, the single-phase transformers being in more general use. Continuous operation of the brine pumps and circulating water pumps is just as essential as continuous operation of the ammonia compressor. The advantage of being able to isolate one of these latter transformers and operate the remaining two is evident.

Ammonia Condensers

The ammonia condenser is generally located on top of the plant out of doors, Fig. 15, and sometimes directly under the cooling tower, which is used where the same water is circulated repeatedly for cooling. In this case the circulating water pumps may also be located in a small pump house on top of the plant and city pressure

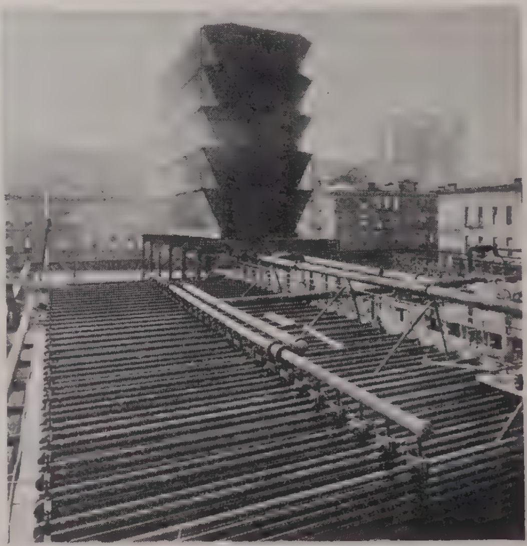

Fig. 15. Air-cooled Water Tower and Brine System on the Roof of a City Ice Plant

is relied on to lift the water to the pump. Where water is pumped from a river or similar source, it is necessary to have a fairly high-head pump for circulating water, sometimes as much as 60 or 70 feet. The head, of course, will directly affect the size of motor required. The squirrel-cage motor running at 900, 1200 or 1800 r.p.m. and direct connected to the pump is used for this service, Fig. 16.

The ammonia condenser in one form consists of a shell of pipes arranged in vertical tiers. Water drops over this shell from a trough located above it. Frequently the sprinkler holes of the trough become clogged with cinders, and the water, instead of passing down over the pipes, overflows at the ends and reduces the effectiveness of the condenser. With the double tube type, this difficulty is avoided by having each ammonia pipe completely enclosed, except at the ends, by a water pipe. Another type of condenser is the tube and shell type which is not unlike a locomotive boiler. Condensers of this type are generally located indoors. Water is pumped into the small reservoir on the top of the condenser and then flows down through long tubes which are open at the bottom. The ammonia vapor contained in the condenser around the water tubes is condensed and drained off at the bottom of the condenser. In a few plants, two-stage condensation is used. Water flowing to the cooling tower is used to cool the ammonia in a small condenser. After the water has been pumped through the cooling tower, it flows over the main condenser where the condensation is completed.

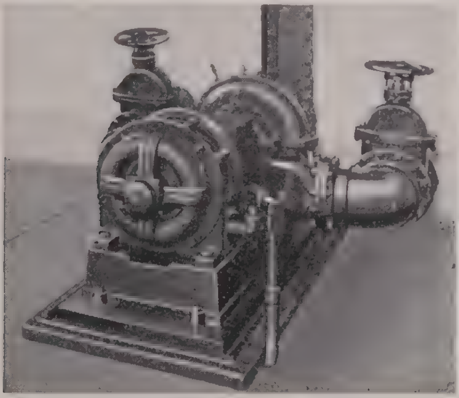

Fig. 16. Direct-connected Motor-driven Centrifugal Pump for Water Circulation

Hoists and Conveyors

The lifting motor of the ice floor crane is a slip-ring motor with a rope-operated resistance control. Where only one can of ice is handled at a time, a hand-operated differential hoist is sometimes used. Occasionally the traveling motor is omitted and the attendant pulls the crane along the track. The chute by which the ice is lowered to the storage room is generally an application for a slip-ring motor. In some cases, however, the motor is eliminated by using a counter-weighted hoist, which will go down when loaded with ice, and will return when the ice is removed from it. A small air cylinder is then used to give a cushioning effect. Where there is more than one ice floor, it is necessary to have an interlock on the elevator so that the loaded hoist coming down from the top floor will not trip the release on the second floor and allow a second load of ice to slide into the elevator shaft. This interlocking is generally handled by a mechanical trip rather than by an electrical interlock. The motors used for the hoists vary from 5 to 15 h.p. depending on the amount of ice to be moved.

Ice Benching Machines

In the storage room a track conveyor is provided for moving the ice cakes across the floor. A squirrel-cage motor of 1 to 5 h.p. is used for this service. Benching machines are also in use in some of the storage rooms where the ice is piled high. Equipments of this kind are furnished with motors built in by the companies who specialize in these accessories.

Ice Scoring Machines

Scoring machines are used in some plants to mark the cakes of ice along the lines where they are later to be split up for distribution. The use of scoring machines is increasing because proper marking of the ice makes it easier to break up the 300-lb. ice cakes into uniform sections, and so reduces the amount of ice lost due to irregular breakage. The scoring is done by small induction motor-driven rotary saws which cut into the surfaces of the ice cake as it passes through the frame of the scoring machine. The driving motor is built into the scoring machine by the manufacturer. A single contactor may be provided for all of the motors of the scoring machine. An overload on any motor will then shut

TABLE I

Machine	Motor	Type of Drive	Control
I. For the ice cans			
(A) Agitation air compressors			
High pressure Reciprocating type	Synchronous	Direct connected	Full voltage automatic, or compensator and field switch
	Squirrel cage	Belted	Compensator
Low pressure			
Positive pressure Rotary blower	Squirrel cage	Direct connected or belted	Compensator or enclosed switch
Centrifugal compressor	Squirrel cage 3600 r.p.m.	Built in	Compensator or enclosed switch
(B) Core suction pump	Squirrel cage	Geared	Enclosed switch
(C) Ice can hoist	Slip-ring or repulsion induction motor		Resistance control
Hoist motor		Geared	Double-throw reversing switch
II. For the brine tank			
(A) Brine circulating pumps	Squirrel cage 900–1200 or 1800 r.p.m.	Direct connected	Compensator or enclosed switch
(B) Brine agitators (vertical propellors)	Squirrel cage 3 h.p., 900 r.p.m.	Direct Connected Vertical	Compensator or switch
III. For the ammonia system			
(A) Condenser			
Circulating water pump	Squirrel cage 900–1200 or 1800 r.p.m.	Direct connected	Compensator
(B) Compressor			
(1) Motor	Synchronous	Direct connected	Full or reduced voltage automatic; reduced voltage manual
	Synchronous	Belted	Reduced voltage, manual or automatic
	Slip-ring	Belted	Resistor drum controller and primary switch
(2) Exciter or		Belted	None
induction motor generator set			Compensator, or connect induction motor across synchronous motor panel terminals
(3) Transformers			
3 single-phase or one 3-phase power transformer			
(4) Main control			
Incoming line and metering panel			
Motor panels			
Exciter panel			
Lighting and distribution panels			
IV. For the ice moving and storage equipment			
(A) Crane	Slip-ring or repulsion induction motor	Built in by crane manufacturer	Rope-operated drum controller
(B) Conveyors	Squirrel cage	Direct connected or chain drive	Enclosed contactor or switch
(C) Ice benching machines	Squirrel cage	Built in by manufacturer	Enclosed contactor or switch
(D) Ice scoring machines	Squirrel cage	Built in by manufacturer	Enclosed contactor or switch

down the scoring machine, and avoid piling up the ice cakes or breaking any of the parts.

Conclusion

The manufacture of a simple cake of ice necessitates a number of operations that are performed in turn by machines that differ widely in the amount and characteristics of their power requirements. This is one of the reasons why they can best be driven electrically. The size and type of the motors and their control equipment, however, naturally varies with the individual application, a convenient summary of which is presented in Table I.

Several departures from the ice-making process as outlined may be encountered in individual plants since innovations are continually being tried out to reduce the labor and thus decrease the cost of the product. Among these may be mentioned the use of automatic pressure control and high-torque motors for the ammonia compressors, and also methods for handling ice cans in groups of 20 or more instead of singly or in pairs.

Lightning Arresters for Transmission and Distribution Circuits

By E. E. Burger
General Engineering Laboratory, General Electric Company

With transmission lines growing longer and distribution networks more extensive every year, adequate protection against lightning disturbances becomes steadily more vital, with the result that intensive theoretical and experimental work is being carried on in this phase of engineering in many parts of the country. Mr. Burger brings forward in the present article some economic considerations of the lightning protection problem, and without entering into technicalities shows by means of an interesting analogy what types of equipment are best adapted to the several classes of service.—Editor.

The selection of lightning arresters for the protection of distribution circuits differs considerably from the selection of arresters for transmission circuits.

In transmission circuits, ordinarily of higher voltages, the lines are long and the apparatus, either generating or receiving, is concentrated at the ends or at some junction point. Most of the surges originate at distant points from the apparatus and are propagated toward the ends of the line as traveling waves. As the wave is propagated along the line, the energy of the wave is slightly diminished by losses in the line and the wavefront is somewhat flattened out by the natural characteristics of the line. The degree of protection afforded at line terminals must be of the highest order, for the reason that not only does the connected apparatus represent a large investment of capital but continuity of service to the larger areas served through the apparatus is of prime importance. Again, station apparatus is usually protected by relatively few arresters, and these arresters, being called upon to protect under most severe and adverse conditions, must be rugged. Arresters of larger area and greater weight, requiring somewhat greater floor space and possibly some attention, are usually required for these installations. Economically, the higher cost of the protecting equipment and the construction of low-resistance grounds is warranted by reason of the greater advantage gained through the absence of shutdowns.

In distribution circuits, the transmitting voltages are usually somewhat lower, the distances between connected apparatus are much shorter, and the network is concentrated in a much smaller area. During thunderstorms the origin of disturbances is at the terminals of the apparatus, and wavefronts are not modified by circuit constants. Leakage conductance over insulators and through transformer insulation allows the accumulated charge on both line and ground wire to be of nearly equal potential, so that the starting wavefronts must be of an order equal to that of lightning itself. For this reason the conditions to be met on distribution circuits in some respects are even more severe than those on transmission circuits. But distribution circuit protection differs from transmission circuit protection in other respects. Continuity of service is usually of less importance because of the nature and size of the load, so that the cost of protection as compared to the initial cost of installed apparatus and revenue derived is a large factor in the selection of an arrester.

It has been shown from service records that as the density of arresters on distribution circuits is increased so is the degree of protection increased. This is obvious because the more arresters that are connected to the system, the more paths there will be to ground through which to drain the charge induced by lightning. However, the length of line between arresters and the surge impedance of each line play important parts in determining the total protection.

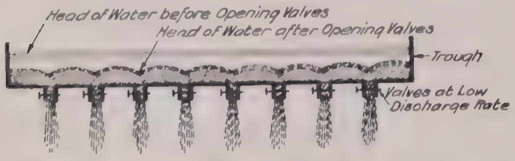
Head of Water before Opening Valves
Head of Water after Opening Valves
Trough
Valves at Low Discharge Rate

Fig. 1. Illustrating Simultaneous Discharge Through Many Small Valves

Now there seem to be two possible ways of applying arresters to distribution circuits. The first is to apply a sufficient number of arresters at short distances apart so that the total induced voltage of the system will be kept at a minimum or below some critical value. The second method is to apply a high-grade arrester having low internal resistance and a high discharge rate at certain points on the system where apparatus is connected and protection is most needed, so that at these particular points the allowable rise in voltage will be limited by the rate of discharge. As a mechanical analogy to these two methods of application we might consider the lines as being represented by troughs filled with water and the water as representing the induced charge. The head of water would represent the potential of the charge. The object in view is to reduce the head of water as quickly as possible. Fig. 1 would represent the method using many arresters. By providing a sufficient number of valves in the bottom of the trough (each valve representing a lightning arrester) the total head of water could be quickly reduced by opening all of them at one time. Fig. 2 would represent the second method, where large valves are located at less frequent intervals. By having each valve large enough so that its ability to discharge is greater than the rate of water flow through the trough, the head would always be a minimum directly over the valve. In this case the resistance of the trough to the flow of water would be equivalent to the surge impedance of the line and the discharge pipe below the valve would represent the resistance of the ground and ground wire.

In applying arresters to a distribution system, a fact which is often lost sight of is that the greatest reduction of potential is at the place where the arrester is connected to the circuits, while even within a few feet of this point a considerably higher potential may be maintained.

Since arresters of high discharge rate are reasonably low in cost, it would seem to be economical to install such arresters at the terminals of every transformer. This method would give a high degree of protection and would keep the total cost of protection at a minimum.

The question of grounds or ground resistance, of course, is vitally connected with the protection problem, but since it seems to be generally understood that no arrester can give good protection through a poor ground, no further mention need be made except in the cases where low-resistance grounds cannot be easily obtained. Here the installation of multiple arresters seems to be the only alternative. But even in these cases it would seem better economy to locate the additional arresters as close to the apparatus to be protected as conditions would permit rather than distribute them evenly along the line.

It is true that little is known as to the exact nature and magnitude of disturbances produced on transmission and distribution circuits, so that in some instances, such as direct strokes of lightning, etc., some failures of both apparatus and arresters are to be expected. The tendency in arrester design is to reduce these possible conditions to a minimum and without prohibitive cost include those qualities which make for high endurance and long life. In the case of both the cell-type and

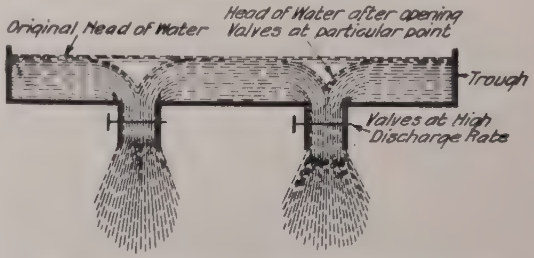
Original Head of Water
Head of Water after opening Valves at particular point
Trough
Valves at High Discharge Rate

Fig. 2. Illustrating Discharge by a Few Large Valves

pellet-type oxide-film arresters, the construction is such that their ability to withstand inherent line surges, such as caused by switching, arcing grounds, short circuits, etc., is a maximum. The principle of operation of these two types is the same, the chief difference being in their relative size. The cell-type oxide-film arrester, because of its larger area and greater quantity of active material, is better able to discharge the larger quantities of electricity which may collect on transmission lines, usually from 30 to 50 ft. above ground and many miles in length. Again, arcing grounds, or low-frequency slightly damped surges which are still possible on many systems, are more readily dissipated because of the heat-absorbing qualities of the cell-type arrester. The pellet-type arrester, although of high discharge rate to short-time transients, does not have as great an endurance as the cell-type arrester, so its application is more suitable to distribution circuits or short lines where the distance between adjacent arresters is not over a mile or two and where arcing grounds are of rather short duration.

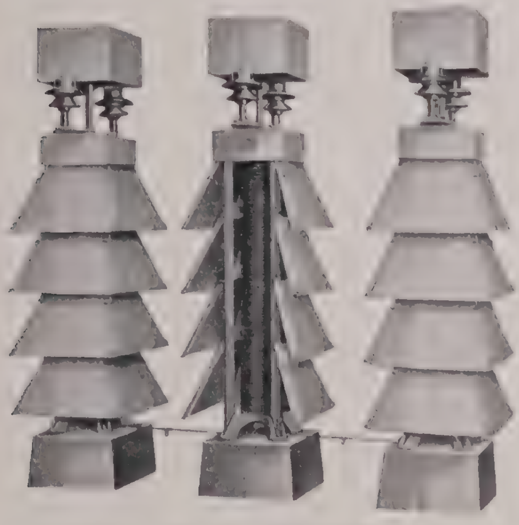

Fig. 3. Oxide-film Lightning Arresters for Outside Service

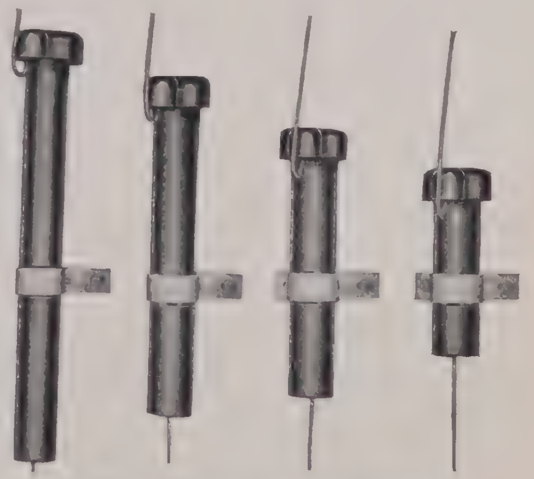

Fig. 4. Pellet-type Oxide-film Arresters

If an arrester failure should occur it must be realized that, even though the circuit is cleared through the operation of circuit breakers and service immediately restored, the circuit is left unprotected at probably a most critical time and apparatus failure with loss of service is possible before a new arrester can be installed. So where continuity of service is a question of necessity, the quality of lightning arrester endurance should not be lost sight of.

Manufacturers of lightning arresters today are making every effort to increase the degree of protection and to lessen the cost of such protection. These features will be brought about through a greater knowledge of line conditions now made possible by newly-developed high-sensitivity measuring instruments.

ERRATUM

In the article "Single-phase Short-circuit Calculations," by W. W. Lewis, that appeared in our issue of July, 1925, page 488, the title of Fig. 13 should have read, "Alabama Power Company, 110,000-volt, 60-cycle Circuits from Lock 12 to Bessemer. Line *A* under test. Line *B* open at both ends."

The Java State Railway Electrification

By J. Ralph Johnson

Contract Service Department, General Electric Company

In the February, 1925, issue of the General Electric Review we presented an article by Mr. Frank Guillot dealing with the control equipment for the electric cars being installed by the Java State Railways on part of its system. The present article will describe the more general features of this electrification. It is interesting to note that the traveling public in this remote island of the East Indies is now able to enjoy a riding comfort, secured to them by the adoption of automatic electrical equipment, which is often found lacking even on the large systems nearer home.—Editor.

Extent

The Batavia suburban section of the Java State Railways was placed under electrical operation on April 7th of this year. This section represents the initial stage of a comprehensive scheme of railway electrification undertaken by the Government of the Dutch East Indies in Java. At the present time there are about 1600 miles of state railways and 1500 miles of privately-owned railways under steam operation in the island; and it is proposed to electrify a large portion of the state railways during the next few years.

The heavy suburban traffic in the neighborhood of the cities and the total lack of coal in Java were the primary considerations which led to electrification, and the existence of several natural water-power sites in the vicinity of the railways made the supply of electric power an attractive proposition. The coal now used on the steam locomotives is transported from the neighboring island of Sumatra and the expense involved in shipping and storage is considerable. Wood also is used as a fuel but the available supply is inadequate for the increasing demands of the railways.

The System

After a thorough investigation of existing electric railway systems in different parts of the world the state railways decided to adopt 1500 volts direct current as being best suited to meet the requirements for suburban and main-line service, and the section from Meester Cornelis to Tandjong Priok was chosen for the initial electrification because of the density of local traffic in this Batavia area. This section comprises 32 single-track miles including parallel tracks and sidings. The major portion is double-tracked but the approaches to the terminal station at Tandjong Priok and the yard at Meester Cornelis have five tracks. The gauge of the line is 3 ft. 6 in. with rails weighing 90 lb. per yard and the maximum curvature is 1300 ft. There is practically no gradient in this section—it is only beyond Meester Cornelis that the grade begins.

Substations

The electrified section is served by two substations about twelve kilometers (7.5 mi.) apart. These substations are fed from a 70,000-volt line 100 km. (62 mi.) in length which brings power from a hydro-electric station centrally located with regard to the general electrification scheme. The high-tension line is three-phase double-circuit, suspended from steel towers by Hewlett insulators; a ground line runs above the power line, connected to the peaks of the towers.

The Meester Cornelis substation has at present a capacity of 3000 kw., supplied by two 1500-kw. synchronous motor-generator sets. At a later date a third similar set will be installed.

The substation building consists of two sections divided by an open-air alleyway through which passes a railway track connecting with the main line for delivery of material to the substation. The first section contains the machine room and the 6000-volt room, the bus of which is connected by means of underground cables to the secondaries of the power transformers housed in the other section. The latter section contains all of the 70,000-volt equipment; on the ground floor are the transformers and oil circuit breakers while the upper floor contains the high-tension bus and disconnecting switches.

A large basement beneath the machine room contains the machine cables, feeder cables, lightning arresters, feeder test resistor and the field rheostats of the machines.

All switching operations are controlled from two switchboards in the machine room. One board controls the 70,000-volt oil circuit breakers and the 6000-volt switches between the transformer secondaries and the 6000-volt bus. The other board controls the machine oil circuit breakers and the d-c.

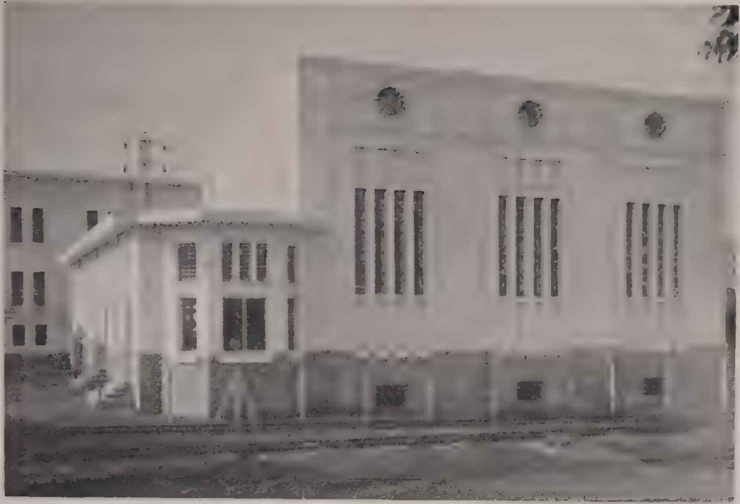

Fig. 1. Exterior of Substation at Meester Cornelis

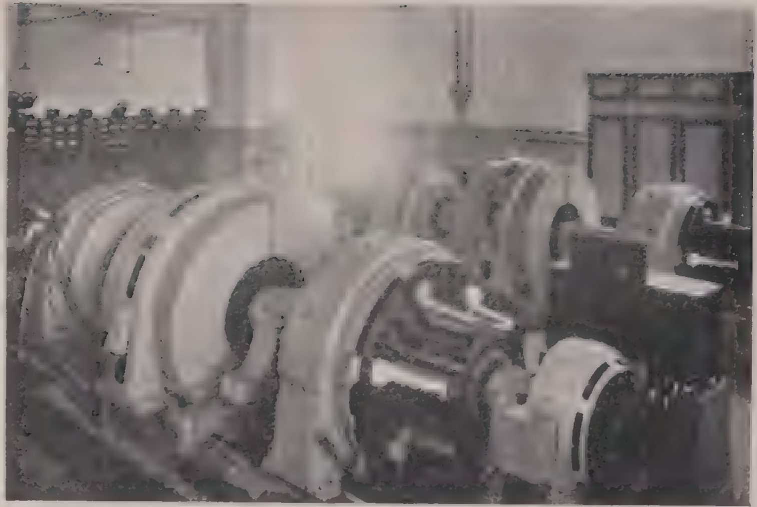

Fig. 2. General View of Machine Room

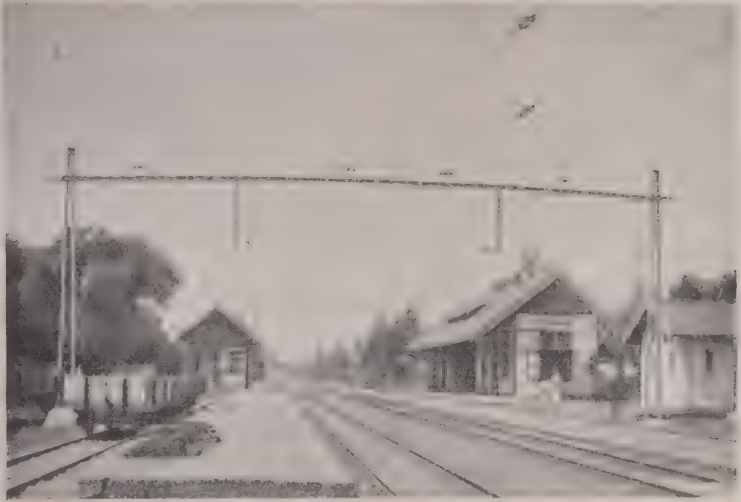

Fig. 3. A Typical Passenger Station

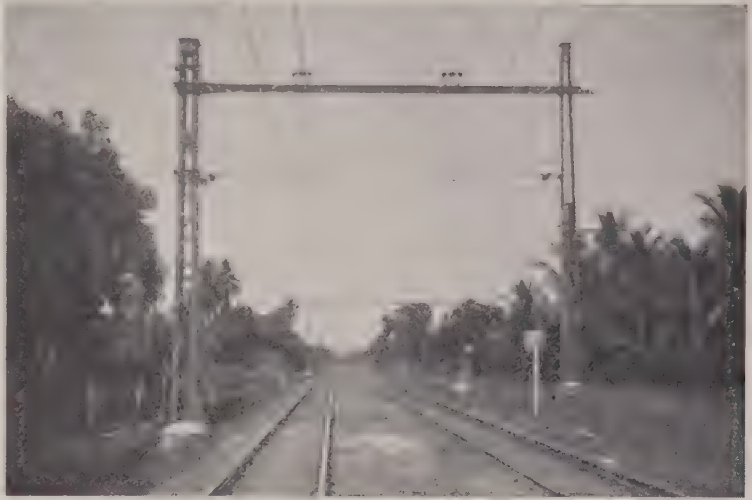

Fig. 4. Tangent Track Overhead Construction, Showing Droppers and Spreader Grip for Trolley Wires

machine and feeder switches. A third switchboard is installed for station service and serves the ventilating fans, air-compressor motor, lighting circuits, battery-charging set, etc., through a 30-kv-a. service transformer. The d-c. control circuits for switching and relay operations are also supplied through this board either from the main machine exciters or from a 125-volt Edison battery.

Motor-generator Sets

Each of the main sets is capable of carrying rated load continuously with a guaranteed temperature rise of 35 deg. C., 150 per cent rated load for two hours with a rise of 55 deg. C., and 300 per cent rated load for five minutes without injurious sparking or detrimental temperature rise. The above temperatures are based on an ambient temperature of 40 deg. C.

The sets are of the three-unit four-bearing type consisting of a synchronous motor with two direct-connected d-c. generators. There are two exciters, one on each end of the shaft. The larger exciter (18 kw.) is for the motor field while the smaller (10.5 kw.) is for separately exciting the generator fields and also the shunt field of the motor exciter. Protection for the motor is provided by overload and undervoltage relays. Power for the synchronous motors is taken from the 6000-volt bus through oil circuit breakers interlocked electrically for "Starting" and "Running." At start the motors are supplied with reduced voltage through compensators. When the machines are up to speed excitation is applied and the motor pulls into synchronism. The running switch is then closed and full voltage placed on the stator. The starting torque is supplied by amortisseur windings of the squirrel-cage type in the pole faces of the rotor.

The motor exciter is compound wound, its series field being excited by the main line current from the main generators and its shunt field excited by the other exciter. By this means a steep rising voltage characteristic is obtained, as the series field predominates. Thus the excitation of the motor field is varied automatically with load and the design is such that a power-factor of approximately 0.9 leading is maintained from 25 per cent to 150 per cent normal load, while at 300 per cent load the power factor is unity. A further advantage of the variation of excitation with load is that maximum torque (and therefore maximum capacity) which varies approximately as the product of line voltage and excitation, occurs at maximum load.

The d-c. generators are compound-wound and are provided with commutating poles and compensating windings in the pole faces. The two armatures of each set are connected in series to give 1500 volts. Both armatures are insulated for 1500-volt operation and are interchangeable.

The series fields of both generators are connected in the ground side of the set and the equalizing connection for the parallel running of the sets is therefore grounded. This facilitates considerably the equalizing operation.

The motor-generator sets are designed to meet the severe load variations which occur in suburban railway service and can deal instantaneously with load changes from no load to 300 per cent load. By the addition of very little equipment the machines will operate reversed for regenerative braking of the rolling stock if future requirements call for this condition.

High-speed circuit breakers protect the generators from short circuits on the line and the remote possibility of flash-over is taken care of by asbestos guards which completely cover the brush-holder yoke and the commutator risers. Barriers are also placed between the brush-holder brackets close to and parallel with the commutator. These prevent arcs from being carried over from the positive to negative brushes under short circuits.

The high-speed circuit breakers are employed in the positive and negative lines close to the generators, and the positive breaker is set to trip on reversed current above a pre-determined value. This might occur if the voltage of a neighboring substation rose above normal for some reason or if the voltage of the first station fell when both stations are operating and feeding the trolley line. Under short-circuit conditions on the d-c. side the negative breaker opens extremely quickly (0.005 to 0.008 sec.) and inserts a resistance in series with the line. This reduces the short-circuit current. This reduced current is then opened by the positive breaker which is electrically interlocked with the negative breaker. By opening the circuit in two steps in this manner the shock to the machine is considerably reduced.

The generator fields are provided with a field-killing device which lowers the d-c.

voltage at time of short circuit by automatically inserting a resistance in series with the generator fields. This device is interlocked with the negative breaker and comes into action on the opening of the breaker.

The 1500-volt d-c. positive bus runs the whole length of the feeder compartment cells which are situated directly behind the main switchboard. These cells house the disconnecting switches and the high-speed circuit breakers in the machine and feeder lines. An auxiliary bus in the lower part of the cells is installed for testing the feeders. Any feeder can be placed in series with the test resistor through the auxiliary bus at any time by means of the disconnecting switches in the cells. If the feeder is grounded the resistor limits the current to 75 amp. with 1500 volts on the bus.

All high-speed circuit breakers are operated by remote control from the switchboard, the control voltage being supplied by the generator exciters. In case of necessity the breakers can be operated by hand.

The positive feeders are led from the disconnecting switches through the wall of the basement and underground to the tracks.

Here five of the cables are led up the supporting poles of one of the trolley gantries and connected to bare copper cables which are supported and dead-ended by insulators on upright brackets on the gantry. From these cables connectors are dropped to feed the various trolley lines above the tracks. The remaining feeders are led into other branch lines. No parallel feeders are employed along the tracks as the copper section of the trolley wire and the catenary is ample to prevent excessive voltage drop.

The negative feeders are bonded to the feet of the track rails and enter the basement of the substation where they are clamped to the negative busbar. A totalizing shunt is placed between the negative bus and the machines and is used in connection with an indicating and recording ammeter so that the current output of the station is measured and recorded continuously.

Overhead Construction

Current for the motor cars and locomotives is conducted through overhead contact wires of the catenary type. The catenary, droppers and trolley wire are made of copper, except at points adjacent to substations where a steel catenary is used without adverse effect on trolley voltage drop. As already stated, the use of a copper catenary and copper droppers obviates the need for parallel feeders to maintain the trolley voltage. It may also be noted that whereas before the introduction of the high-speed circuit breaker it was usually necessary to install parallel feeders tapping into the trolley at some distance from the substation so that under short-circuit conditions there was sufficient resistance in the feeder to limit the short-circuit current within commutating limits of the generators until the circuit breaker opened, the absence of the long feeders in modern systems is taken care of by the extreme rapidity of opening of the high-speed breakers.

Two contact wires are used over each track. The cross-section of each is 107 sq. mm. (147,000 cir. mil) and the section of the stranded catenary is 150 sq. mm. (205,000 cir. mil). Thus the effective sectional area is 364 sq. mm. which corresponds to 550,000 cir. mil.

The contact wires are supported at intervals of 12.5 m. (41.25 ft.) by copper droppers from the catenary. Two types of droppers are employed, one with a spreader grip which supports each trolley wire and which, by use of spreaders of varying span, varies the distance between the two wires; the other type uses no spreader, and each wire is supported by individual droppers alternately connected to the catenary. In this case the contact wires are parallel but are staggered on the cross-supports between the poles. In each type therefore the contact wires are arranged to prevent grooving of the pantograph collector by varying the point of contact.

The contact wires are maintained in constant tension at 400 kgm. per sq. cm. (5690 lb. per sq. in.) by cast-iron weights attached to and insulated from the wires at distances of 1 km. (0.62 mi.). Temperature changes are thus provided for. The tensioning devices are located on special steel anchor poles at intervals of 1 km., and the intermediate supporting lattice steel poles are spaced 75 m. (246 ft.) apart. The overhead construction is supported on and insulated from steel bridges, the catenary wire passing over the top of the cross-beams on which the insulators are placed.

Track Bonding

A welded type bond is used for the track rails and the welded joint is made between the head of the rail and the solid end of the bonds. The copper section of the bond is 200 sq. mm. (about 275,000 cir. mil).

The track rails are cross-bonded every 100 m. (328 ft.) with copper cable of section 100 sq. mm. (137,500 cir. mil) welded to the feet of the rails, and the rails are connected to the ground plates at intervals of 400 m. (1312 ft.) by cables of similar section. All the steel poles are grounded to the track rails by cables of 25 sq. mm. (34,375 cir. mil) section connected to the rails by means of an expanded terminal bond.

Rolling Stock

For the initial section between Tandjong Priok and Meester Cornelis, there have been supplied 15 motor-car and 15 trailer-car equipments. The cars are to be used for fast local service and are suitable for operation in multiple-unit trains. Under normal running each motor car will pull one trailer, and this combination forms one unit controllable from either end. The cars and equipment are built to withstand a maximum speed of 90 km. per hr. (56 m.p.h.); normal operating conditions will call for a maximum speed of 75 km. or 46.6 mi. per hr., on tangent track and an average speed of 60 km. per hr. (37.3 m.p.h.). Normal acceleration is approximately 2 ft. per sec.. This acceleration is automatic and its value depends on the setting of the accelerating relay. By cutting out the automatic accelerating feature the train can be accelerated at a higher rate in case of emergency.

The motor-cars are provided with two 4-wheel trucks each carrying two motors rated at 115 h.p. at 750 volts. The motors are of the box type designed to operate two in series with line voltage at 1500, and all motors are insulated for 1500 volts. The motors are mounted in the trucks on the nose-suspension system, the projection on the motor frame resting on a bracket fixed to the transom. Power is transmitted to the driving wheels by the standard pinion and gear drive with gear ratio 67:20. The gears are made from special high-grade steel and the pinions of specially treated steel. The motors are self-ventilated, the cooling air entering the frame through screened openings at the pinion end and passing round the field coils and over the armature to the commutator end. The air then returns through longitudinal holes in the armature and commutator and is forced out of the pinion frame head by a fan cast integral with the armature. A deflector prevents the mixing of the incoming and outgoing air. A point of interest in the motor bearings is the use of a thin layer of babbitt metal sweated to the inside of the bearing. In case of over-heating the babbitt runs out and its thickness is such that the armature is prevented by the bearing shell from striking the pole pieces.

A feature of the cars is that in addition to the compressed air brakes and hand brakes, rheostatic braking is also provided. A special braking switch can be used to change the motor and control connections so that when necessary the motors can be cross-connected for generator action and loaded with the starting resistors. The same switch also provides the means to cut out either pair of motors in case of trouble. When braking, the motor fields are cross-connected so that the fields of each pair of motors are excited by the armature current of the other pair and thus each takes its proper share of the load. Without this cross-connection the machine which first excites would de-magnetize the other and reverse the e.m.f. causing a short circuit on the excited machine.

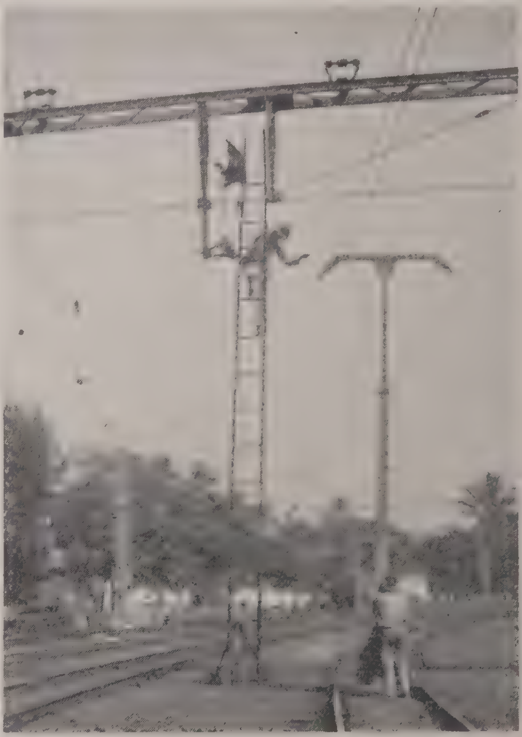

Fig. 5. Overhead Construction, Showing Gauge Used for Locating Position of Trolley Wires

Control

The Sprague General Electric system of control is employed.(1) In this system the operation of the motor controller which handles the motor currents is governed by a master controller on the motor car or on the trailer depending on the direction in which the train is going. The individual contactors on the motor controller are actuated by a pneumatically-operated cam shaft which secures an absolutely definite sequence of closing and opening. The control is completely automatic with the advantage of uniform acceleration which means comfort for passengers, and power saving. The master controller operates directly through train wires and on the first notch the motor reverser and line breaker closes, while the cam shaft on the motor controller moves to the first position, closing the contactors for the first step of the starting resistance. Magnet valves excited through the master controller control the inlet and exhaust of compressed air to cylinders, and the movement of the pistons actuates the contactors. The line breaker and the reverse are provided with individual cylinders and magnets and there is one air engine for the cam shaft which actuates all starting contactors. In normal operation the master controller is thrown to full running position and the current-limit or accelerating relay controls the subsequent movement of the cam shaft, thus controlling the acceleration of the train. This relay provides the automatic current-limiting feature by keeping its contacts open so long as the motor current at each step of the motor controller remains above a pre-determined value. In case of necessity the motor controller can be notched up and held on any desired point as in the case of non-automatic control. This is accomplished by means of an advance lever on the master controller cap plate and a by-pass feature on the accelerating relay.

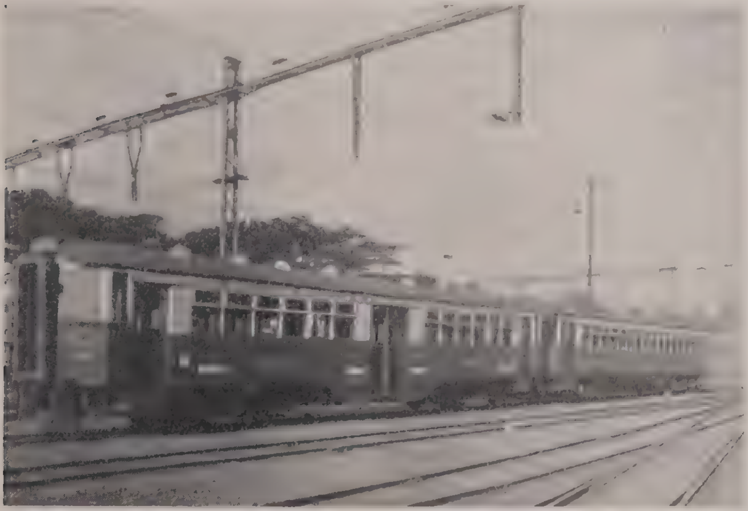
Fig. 6. Train Unit, Motor Car and Trailer

Current for the control circuits, lighting circuits and the ventilating fans is provided by a motor-generator set at 65 volts. The motor of the set has a double-wound armature and two commutators connected in series for 1500-volt operation. The generator voltage is maintained constant by means of a regulator operating on the generator field. The regulator control magnet is connected in series with a resistance across the generator field and operates to cut in or out a counter-e.m.f. motor whose armature is in series with the generator field. The voltage of the counter-e.m.f. motor opposes the generator field and when cut in by the control magnet it reduces the voltage on the generator from full-field value to the value for which the regulator is set to hold.

A storage battery is provided for emergency lights and control in the event of power failure. Normally the battery floats across the generator and is automatically cut in or out of the generator circuit as required, by means of relays.

Air Compressor

A motor-driven air compressor suspended in a cradle beneath the car supplies air for braking and for pneumatic control equipment. The motor is wound for 1500 volts and is connected to a single-stage air compressor with duplex cylinders, through herring-bone gearing. A special governor provides for synchronous operation of all compressors in the train and the compressors are started and stopped automatically with variation of pressure in the reservoirs. Each compressor has a capacity of 36 cu. ft. per minute, and two pipe lines are installed, one connecting the reservoirs and the other the common train pipe-line. The brakes are of the standard compressed air type as used extensively in the United States.

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(1) A more complete description of this particular application will be found in an article by F. Guillot, GENERAL ELECTRIC REVIEW, Feb., 1925, p. 95.

Current Collector

Two pantograph current collectors are provided on each motor car, each of which is designed to operate the train, so that one may be regarded as a spare. The frame which supports the collecting shoes is made of standard welded steel pipe with malleable iron joint castings. The overall length of the trolley is reduced to a minimum by having the bottom frame arms crossed. The collecting head consists of two shoes each provided with eight copper wearing strips attached to a sheet iron pan. This pan is filled with graphite grease to reduce friction. The length of the wearing surface is 48 in. and the total length of the pan including the aluminum horns at the ends is 6 ft. 8 in. Each horn is provided with a hole in which a stud may be inserted to prevent the contact wire from sliding off. All bearings throughout the trolley are of the clevis and pin type except the main shaft which has roller bearings. Every bearing is provided with a shunt of copper strand.

The pantograph is operated by means of air pressure and is under the control of the motorman. The operating mechanism consists of four nested springs, two air cylinders, two operating shafts, two pipe main-shaft equalizers and a quick release valve. The pantograph is raised when air is admitted to the air cylinders and is held against the contact wire with a pressure of approximately 28 lb.

Should the necessity arise the pantograph may be raised by means of a hand pump installed in the motorman's cabin. The required pressure for raising the pantograph can be attained by hand in 30 seconds.

Studies in the Projection of Light

PART XVIII

THE SECTIONAL PARABOLOIDAL MIRROR

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

Historically, the sectional mirror perhaps ranks next in age to the plane mirror, but it has many interesting properties that are not widely appreciated. It is preëminently the mirror for the production of a wide and soft edged beam free from images, and it has found wide acceptance in outdoor floodlighting and in studio illumination. As the author points out, the optical principles of the mirror differ fundamentally from the other conics so far discussed in this series and entirely different methods are employed in making the analysis. The sections may be designed to be laid tangent to the basic paraboloid, or they may be made to fit inside, touching only at the corners. The latter form is more complicated to analyze, but much simpler to manufacture, and is therefore given preferential treatment. The theory of the chord system of sections will be developed more fully in a subsequent installment.—Editor.

Introduction

There is a legend, which will not down, that at the siege of Syracuse the Roman fleet was burned by rays from a mirror built by Archimedes. This story may well be true, for it is a feat possible for anyone provided with a number of plane mirrors, a knowledge of geometry, patience, bright sunshine and an obliging and punctual enemy in a wooden ship. True, the legend is not always specific as to details, but of the paraboloidal form we may be certain, and it is not difficult to conjure up the authentic details of the entire achievement.

First, the inspiration, and who can withhold the credit for this one inspiration from a man whose life seemed to be a long series of inspirations? Besides, it is one of the attributes of greatness to gather more and more credit as the centuries go by and we might just as well stop doubting now and admit the fact. Plane mirrors are always found within arms length of beauty, and with the backing of a disciplined army at hand there is little reason to think that Archimedes lacked polished mirrors of gold and silver. Next came the construction of a large wooden paraboloidal frame at the point where the enemy would attempt to land and on the water in front of the frame a temporary target was anchored. The frame was held in gimbal rings and in its center the first mirror was placed. Then Archimedes, perhaps at "rosy fingered dawn," began the mounting of the plane mirrors, each successive one being adjusted to reflect the sun's rays to the point covered by the central one, and then covered with cloth so that a premature fire would not give warning to the Roman fleet. This work was necessarily carried out at the time of day at which the enemy was expected to land and the success of the venture depended upon the Romans attacking on schedule time. They did, with the happy result in the legend, and although Archimedes did not save the city he did a greater thing—he built the first sectional mirror of paraboloidal form.

With this historical background it would seem that everything possible has been said about, and everything practical has been done with, the sectional mirror, but such is not the case. Much excellent design work has been done and some very worthy samples of this mirror are in everyday use, but as often happens with things that are too simple and commonplace, the basic theory has seemingly been neglected. In the following paragraphs a brief outline of some of the more important properties are given, but there is no effort at completeness, for there are innumerable variations possible, and space will not permit a discussion of more than a few of the more obvious types of design.

Nature of the Beam from a Sectional Mirror

The striking features of a beam from a sectional mirror are its softness of outline, uniformity of intensity, and relative freedom from images of the source. These features are often of extreme value, but they are attained at the expense of beam strength, so that to the above list might be added low intensity and a wide angle of spread. The projection efficiency is ordinarily high, therefore for short range projection the floodlight built on the sectional plan stands without a superior. The beam formation takes place in a manner radically different from the parabolic and hyperbolic beams and as the analysis of the beam involves new points of view, it is necessary to begin a survey of the subject with the very elements of reflection by a plane mirror, and by some process of summation arrive at the beam from the complete reflector.

The various beams of the conic family so far discussed have one point in common—they come from a single real or virtual image. The sectional beam, however, radiates from a multitude of images and the whole beam therefore is composed of a multitude of individual beams that, at a sufficient distance, merge into one. The beam coming from a multiple-imaging mirror lacks all the details that are peculiar to the image forming conics, and with the sole exception of the beam diameter or outline, the beam gives no clue to the form or brightness of the source. The central beam intensity is a function of the intensity in candles of the source regardless of its size or form, and the specific brilliancy of the source has no bearing on the intensity of the beam.

The Unit Beam

Each flat section of mirror in the sectional mirror reflects an independent beam of light whose cross section resembles the outline of the section of mirror and whose strength in candles is proportional to the intensity of radiation from the source in the direction of the plane mirror in question. Let this intensity of radiation from the extended source be I_a, and let the coefficient of reflection of the mirror be K, then the strength I_e of the elemental beam is

$$I_e = K\ I_a \text{ candles} \qquad (357)$$

If the centers of the elemental beams are substantially parallel then at some distance they will all overlap and, adding the direct radiation of the lamp, the combined beam strength is

$$I = \Sigma K\ I_a + I_{180} \text{ candles} \qquad (358)$$

Thus with a source giving 1000 candles uniformly in all directions, and a 36-section mirror of glass having a coefficient of 0.85, the beam strength is

$$I = 36 \times 0.85 \times 1000 + 1000 = 31{,}600 \text{ candles}$$

of which 30,600 is the strength of the reflected light and 1000 is direct radiation from the source. Fig. 212 is a photograph of such a sectional mirror with the light source in the center and the 36 images in the 36 sections arranged in three concentric circles. In this actual case the intensity of radiation is not equal in all directions about the source, and the direct radiation along the axis of the beam is far below the average, as is clearly indicated in the photograph. In computing this beam each zone of mirrors must be used in connection with the correct intensity as shown by the distribution curve of the lamp, and for this reason the summation indicated in equation (358) is more than a simple counting of sections.

Conditions for Maximum Beam Uniformity

Spherical Source

A condition that might be regarded as of prime importance is the attainment of a high degree of uniformity at all points in the strength of the beam. The beam from a paraboloid ordinarily has a center of nearly uniform intensity, the crest, but the beams from ellipsoids and hyperboloids are always most intense in the center with gradually decreasing strength toward the edge. As these latter reflectors are the ones often used when great beam width is desired, the intensities in a wide beam are usually far from uniform. It is in this particular field that the sectional mirror is most useful and it is here proposed to see what physical proportions the mirrors must have in order to produce the greatest degree of beam uniformity. The computations of the angular dimensions of the sections of a sectional mirror do not call for any great degree of accuracy. This condition allows a number of simplifications to be made in the formulas, all of which do not follow orthodox lines. An attempt to follow a rigid mathematical treatment soon leads to such complicated forms as to discourage the most conscientious designer, and therefore the simple forms here given may be of far greater practical use.

Obviously, the width W_l of the beam from a single mirror measured in a meridian plane, is equal to the angular length, l, of the mirror, plus the angular width s of the source as measured from the center of the section.

$$W_l = l + s \text{ deg.} \qquad (359)$$

If the edges of the section are formed by meridian planes, spaced p deg., then the angular width, w (= sagittal angle) of a section whose center is at the angle a on the generating parabola is

$$w = p \sin a \text{ deg.} \qquad (360)$$

and the width of the reflected beam is

$$W_w = p \sin a + s \text{ deg.} \qquad (361)$$

The first apparent condition for maximum uniformity is then

$$W_l = W_w \text{ deg.} \qquad (362)$$

If the light source is spherical, and of width s_o deg. as measured from the vertex of the paraboloid, then at any angle a equations (359) and (361) must give identical values:

$$l + s_o \cos^2 \frac{a}{2} = p \sin a + s_o \cos^2 \frac{a}{2} \text{ deg.} \qquad (363)$$

and this equation is then the basis for finding the proportions of the various sections. To have the width W_l equal at the generating center angles, a, b, c, etc., we have

$$\left.\begin{aligned} W_l &= l_a + s_o \cos^2 \frac{a}{2} \\ &= l_b + s_o \cos^2 \frac{b}{2} \\ &= l_c + s_o \cos^2 \frac{c}{2} \\ &\text{etc.} \end{aligned}\right\} \text{deg.} \qquad (364)$$

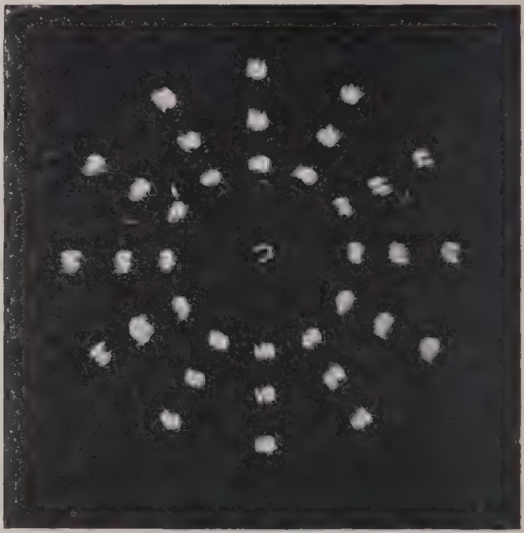

Fig. 212. A View of the Lamp Filament Surrounded by Thirty-six Images in the Thirty-six Sections of the Mirror

and the corresponding widths of sections are

$$\left.\begin{aligned} W_w &= p_a \sin a + s_o \cos^2 \frac{a}{2} \\ &= p_b \sin b + s_o \cos^2 \frac{b}{2} \\ &= p_c \sin c + s_o \cos^2 \frac{c}{2} \end{aligned}\right\} \text{deg.} \qquad (365)$$

To take a specific case let us assume that a beam of 45 deg. width is desired, and that the spherical light source subtends an angle of 15 deg. from the vertex of the generating paraboloid.

$$s_o = 15 \text{ deg.}$$

The vertex of the paraboloid may be covered by a single mirror cut in a polygonal form so that its angular diameter is

$$l = 45 - 15 = 30 \text{ deg.}$$

The second zone of mirrors then starts at 15 deg. from the axis, and we may assume that the center of the zone will be at 30 deg. from the axis. From equation (364)

$$45 \text{ deg.} = l_b + 15 \cos^2 15 \text{ deg.}$$

$$\text{or } l_b = 45 - 14 = 31 \text{ deg.}$$

The inner edge of the third zone is at $15+31=46$ deg. and again we assume some value l_c so as to make the second correction in l for the varying angle formed by the source. Take $l_b=32$ deg., then the center of the third zone is at $46+16=62$ deg. and

$$45 = l_c + 15 \cos^2 31 \text{ deg.}$$

$$l_c = 45 - 11 = 34 \text{ deg.}$$

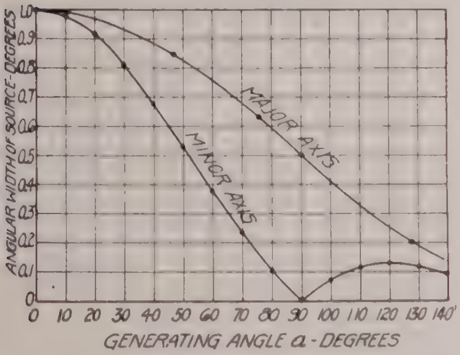

Fig. 213. The Relation Between the Generating Angle a and the Angular Width of the Source as Measured from Various Parts of the Mirror. The upper curve applies to a spherical source and the major axis of a disk source, while the lower curve applies only to the minor axis of a disk source in correcting for the length of the sections

The inner edge of the fourth zone is at $46+34=80$ deg. and the length of this zone may be estimated at 36 deg. and equation (364) used again to determine l_d.

These successive approximations may be made by the aid of Fig. 213 where the angle subtended by a spherical source of diameter 1 deg. as measured from the vertex is plotted to show the relation between s and the generating angle a. Thus, at 0 deg. the source in the above example contributes 15 deg. to the beam width, but at 90 deg. the added width is 7.5 deg. and at 120 deg. only 3.75 deg. With these corrections made all zones will give nearly the same width of beam. Two factors have been omitted in thus computing the beam width. These are the added width due to the corners of the sections extending out farther than the ends of the two center-lines, and the decreased width due to the application of the ten per cent rule to the determination of the edges of the soft edged beam. Later, when the graphical analysis of the beam is taken up it will be determined to what extent these two corrections cancel each other.

The width of the section of mirror is dependent upon the generating angle a, as given in equation (365) and therefore each zone should contain a different number of mirrors. It will be observed that the additional width due to the size of the light source, as given in equations (364) and (365), has an equal influence on the two dimensions of the sections, and therefore no influence at all upon their relative values in the same zone. Substituting the numerical values previously obtained for the central angles, a, b, c, etc. the values of p_a, p_b, etc., are found to be 360 deg., 60 deg., 38 deg. and 40 deg. Dividing these widths into 360 deg. the number of mirrors in the successive zones are found to be 1, 6, 9 and 9. The general rule is that a single mirror suffices in all cases to cover the apex of the paraboloid, and the number of mirrors reaches a maximum at 90 deg. and then decreases to a theoretical single mirror when the edge of the paraboloid is at infinity, that is, when the generating angle approaches the hypothetical condition of equaling 180 deg. See Table XXII.

In the construction of a mirror from the above data it would seem that the most practical thing to do would be to use eight sections, or perhaps ten, in the three outer zones. This would make the mirror easier to construct, and it would not reduce the number of active sections or the central beam intensity. Table XXIII gives some of the angles in the simplified design.

There are here three designs to choose from, and the choice will be influenced by the beam formation, which includes such factors as uniformity of intensity, width and central intensity. These factors can best be evaluated after the beam characteristic has been determined, and this subject will be returned to later.

Disk Source

The proportions of the sections in a mirror to be used with an arc, or disk source, are influenced by the fact that from the outer parts of the mirror the source seems to be elliptical in outline. In making allowance for the width added to the beam by the dimensions of the arc (or monoplane filament) it will be realized that the long axis of the ellipse adds to the spread of light from the ends of the transverse axis of the mirror section, while the short axis adds to the spread due to the length of the section in the meridian plane.

The minor axis of the ellipse is equal to the major axis reduced by the factors cos a, cos b, etc. where a, b, etc., are the angles from the vertex, and equations (364) and (365) therefore become, for a disk source

$$\left.\begin{aligned} W_l &= l_a + s_o \cos^2\frac{a}{2}\cos a \\ &= l_b + s_o \cos^2\frac{b}{2}\cos b \\ &= l_c + s_o \cos^2\frac{c}{2}\cos c \\ &\text{etc.} \end{aligned}\right\} \text{deg.} \qquad (366)$$

and

$$\left.\begin{aligned} W_w &= p_a \sin a + s_o \cos^2\frac{a}{2} \\ &= p_b \sin b + s_o \cos^2\frac{b}{2} \\ &= p_c \sin c + s_o \cos^2\frac{c}{2} \\ &\text{etc.} \end{aligned}\right\} \text{deg.} \qquad (367)$$

It should be noted that the size of the source plays a part in the relative dimensions of the sections because the factors of s_o are not the same in equations (366) and (367) and in this respect the design will differ from that for a spherical source.

Chord or Tangent?

In the sectional view in Fig. 214 the tangential mirrors are seen to leave open joints at the ends of the sections. This is not a desirable form of construction and if an attempt is made to bring the ends together the optical adjustment of the zones will be destroyed. It is therefore necessary to find some other method of construction. The basic point in determining the size and position of each section is its point of tangency to the generating paraboloid. If, however, we change our method of approach and assume the junction points to be on the paraboloid, then there is no point of tangency and the mathematical relations are altered. This construction on the basis of chords is much to be preferred and is one often used in practice.

The equations for determining the angular width and length of the sections in order to secure uniformity remain unaltered when dealing with chords in place of tangents, but as will be seen later, a slightly different interpretation must be given to the angles and a different value is found for the focal length.

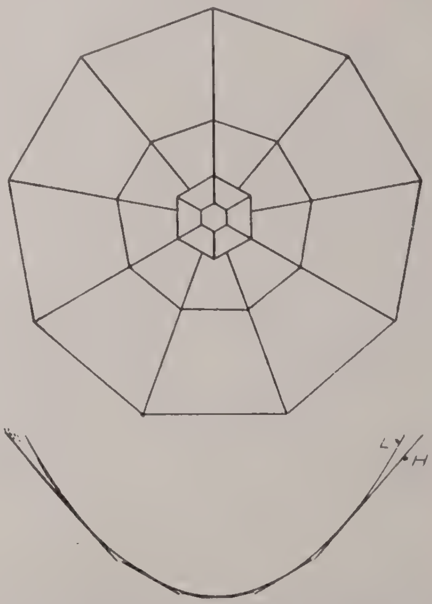

Fig. 214. A Sectional Mirror Built on the Tangent System Does Not Have the Ends of the Section in Contact. The mirrors in the various zones number one, six, nine and nine. Manufacturing considerations require mirrors whose ends join and equal numbers in all zones except the center one. Note that the point of tangency (the optical center of the mirror) between the Curve L and the Section H falls near the inner edge of the section

Use of Chords

Mirror sections of 30-deg. lengths and bounded by meridian planes spaced 30 deg. are shown in Fig. 215 along with the generating paraboloid. Only the corners of the sections touch the paraboloid, and the ends of the sections are chords of circles, while the

TABLE XXII

ANGULAR WIDTH AND LENGTH OF SECTIONS FOR GREATEST UNIFORMITY OF BEAM

15-deg. Source

Zone No.	From Deg.	To Deg.	Center Deg.	Length Deg.	Source Deg.	Beam Deg.	Meridian Deg.	Mirrors in Zone
1	−15	+15	0	30	15	45	360	1
2	+15	+46	31	31	14	45	60	6
3	+46	+80	63	34	11	45	38	9
4	+80	+119	100	39	6	45	40	9

edges are chords of the paraboloid. The optical properties of the center line of each section are of prime importance and the adjustment of section and light source must be made from the data of the center lines.

The height, or y value of a point on the center of the end of a section of width p deg. is

$$y_1 = y \cos \frac{p}{2} \tag{368}$$

as illustrated in Fig. 215, and if all zones contain the same number of mirrors then p is a common angle for all, and the relation between y and y_1 is constant for all parts of the paraboloid. Placing this value of y_1 in the equation of the parabola, we get

$$\frac{y_1^2}{\cos^2 \frac{p}{2}} = 4\,F\,x$$

$$y_1^2 = 4\,F\,x \cos^2 \frac{p}{2} \tag{369}$$

and this is the equation of a new parabola that passes through the junction points of the various center lines. The focal length of the derived parabola is

$$F_1 = F \cos^2 \frac{p}{2} \tag{370}$$

and the light source should therefore be moved toward the vertex accordingly. The generating and derived parabolas have a common vertex and the origin for measuring F and F_1 is a common origin.

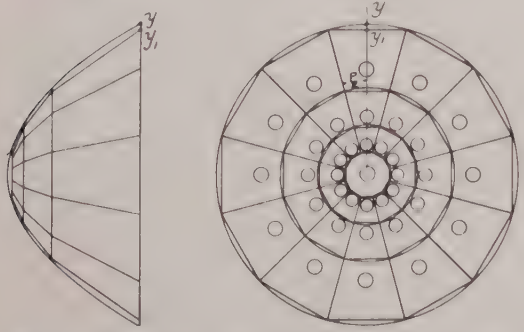

Fig. 215. A Sectional Mirror Built on the Chord System and Having All Sections of Equal Angular Length. The locations of the images are shown by circles. Note that they do not fall in the centers of the sections

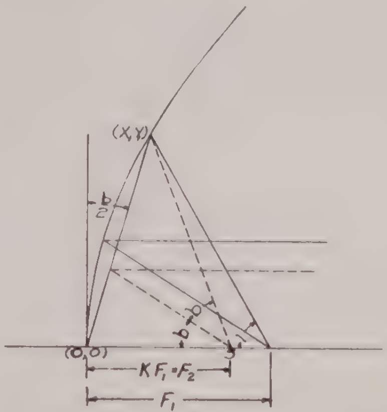

Fig. 216. Diagram Showing the Location of the Source so That the Axis of the Reflected Beam will Coincide with the Axis of the Complete Sectional Mirror

If a chord in a meridian plane is investigated for reflection of light originating at the focus it will be found that the axis of the reflected beam is obviously not that best adapted for giving the best concentration of light, and the equation derived below gives a further shift of the focal point to bring one particular mirror zone into optical adjustment.

In Fig. 216 the parabola is the one derived to pass through the ends of the meridian center lines, and the section extends from the vertex to a point (x_1y_1) at an angle l from the axis. Then

$$x_1 = \tan^2 \frac{l}{2} \tag{371}$$

and

$$y_1 = 2 \tan \frac{l}{2} \tag{372}$$

TABLE XXIII

ANGULAR WIDTH OF SECTIONS IN SIMPLIFIED DESIGN

Zone No.	EIGHT MIRRORS PER ZONE				TEN MIRRORS PER ZONE			
	Meridian Angles	SAGITTAL ANGLES			Meridian Angles	SAGITTAL ANGLES		
		Effect.	Source	Total		Effect.	Source	Total
1	360	30	15.0°	45.0°	360	30	15.0°	45.0°
2	45	23	14.4°	37.4°	36	18	14.4°	32.4°
3	45	40	11.0°	51.0°	36	32	11.0°	42.0°
4	45	44	6.2°	50.2°	36	35	6.2°	41.2°

Let $\frac{b}{2}$ be the angle between the chord from (O, O) to (x_1, y_1) and the tangent at the vertex, then

$$x_1 = y_1 \tan \frac{b}{2} \qquad (373)$$

$$\tan \frac{b}{2} = \frac{x_1}{y_1} = \frac{\tan^2 \frac{l}{2}}{2 \tan \frac{l}{2}}$$

$$= \tfrac{1}{2} \tan \frac{l}{2} \qquad (374)$$

Let the light source be placed at some point S at a distance F_2 from the vertex (Fig. 216) so that the entire chord subtends an angle $2b$. When this condition is fulfilled the rays reflected at the (O, O) point will have a downward slope equal to the upward slope of the ray reflected at (x_1, y_1). The downward slope is seen to be fixed and equal to b degrees because the ray striking at (O, O) does so at zero angle and is deflected by twice the angle between the mirrors and the plane at the vertex, that is, twice b.

Referring to Fig. 216, we can write

$$(KF_1 - x_1) \tan 2b = y_1$$

$$KF_1 = \frac{y_1 + x_1 \tan 2b}{\tan 2b} \qquad (375)$$

By the aid of equation (374) angle b can be expressed in terms of angle l, and these values substituted in equation (375) give an infinite series

$$KF_1 = 1 - \tfrac{1}{4} \tan^2 \frac{l}{2} - \tfrac{1}{4} \tan^4 \frac{l}{2} + \ldots \qquad (376)$$

If this value for the new focal length is substituted in the expression for the generating parabola we get

$$F_2 = \cos^2 \frac{p}{2} \left(1 - \tfrac{1}{4} \tan^2 \frac{l}{2} - \tfrac{1}{4} \tan^4 \frac{l}{2} + \ldots\right) F \qquad (377)$$

for the correct focal point for the first zone of mirrors.

It will be noticed that the equation for F_2 was derived for a zone extending from the axis outward and not for a zone entirely removed from the axis. The equation cannot, therefore, be expected to hold accurately for all zones, but a number of trials have shown it to be as correct as need be for the design of this type of mirror, where 1 deg. plus or minus is not of great importance.

In Fig. 217 several curves give the focal length F_2 when l and p vary from zero to 40 deg. A mirror section 30 deg. by 30 deg. reduces the focal length to 91.5 per cent of the focal length of the generating parabola, while sections 40 deg. by 40 deg. reduce it to 85 per cent. These reductions are of considerable importance because it is customary to make the focal length as small as will permit the use of some predetermined lamp bulb, and unless proper account is taken of the difference between F and F_2 it will not be possible to bring the lamp to the focal point of the finished reflector.

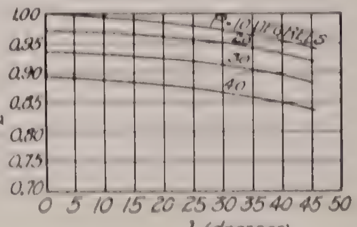

Fig. 217. The Shortening of the Focal Length Depends Upon the Angular Length l and the Angular Width p of the Sections

In case the several mirror zones contain different numbers of sections it would seem the wise thing to take the combination of m and l that gives the smallest value of F_2, and thus guard against the lamp bulb coming against the mirror when focused. An additional reason is the loss of space due to the clips or other fasteners that hold the mirrors in place.

If the light source is shifted to the new focal length F_2 all the angular relations will be altered in some degree. The purpose of the change is to make the upward and downward reflection equal for the top and bottom edges of the same section, but additions to the upward angle will not be exactly balanced by the lessening of the downward angle and the total width of the beam will be slightly altered. This alteration is in the nature of a second order correction (that for the size of the light source being of the first order) and is not of sufficient size to warrant going through the design a second time in order to compensate for it.

(To be continued)

The Pittsburgh Railways Company Receives the Charles A. Coffin Foundation Award for 1925

The Pittsburgh Railways Company, which operates street cars in and about Pittsburgh, Pa., was awarded the Charles A. Coffin medal and prize for 1925, at the recent American Electric Railway Association convention in Atlantic City. This recognition takes the form of a gold medal, a certificate and $1000 in cash, and is awarded annually by the Charles A. Coffin Foundation to the electric railway which during the current year has excelled in outstanding accomplishments.

Scarcely a year has passed since the Pittsburgh Railways Company emerged from receivership. For the preceding twenty years it had been in difficulties and had piled up annual deficits. When Arthur W. Thompson, president of the road, took it out of receivership on February 1, 1924, he announced a policy of working with the public and expecting the public to work with him in the conduct of the road. He started to make good this policy by buying many new cars, reducing fares where possible, re-routing cars where it was deemed to the advantage of the riders, and telling the public about his road through every conceivable advertising means. The public quickly responded by reducing the road's taxes, including heavy paving charges, granting fares which assured a profit, abolishing downtown motor parking, and otherwise co-operating to the fullest extent of its ability.

A strike which occurred soon after the company was brought out of receivership was settled amicably in about three days by fair dealing with the men. Today, the employees are the company's strongest boosters.

A big factor in winning public good will has been the frankness displayed by the management. It is anxious that the people should know all about the property, and there is no legitimate extreme to which it will not go in order to present the facts. Virtually every kind of paid advertising, including newspaper, car card, and billboard space, is used. Much of the space is given to advertising municipal activities, boosting the police and fire departments, and otherwise creating good will by discussing folks and things not directly connected with the company. Considerable space has been devoted to acquainting the riders with the employees. Public talks were used extensively in telling the company's story. From February 1, 1924, to June 23, 1925, members of the commercial department gave 282 addresses; and during the same period operating officials of the transportation department appeared before 540 public meetings.

Particular attention is paid to the suggestions and complaints of individuals. Employees and riders are invited to make suggestions for improving the service. During the last year more than 33,000 suggestions were made by employees. A considerable number of these suggestions were adopted and the persons who made them were remunerated. It is also made easy for any individual to see company officials.

Various rates of fare have been put into effect. It is the management's conviction that the man who rides most frequently should get a bargain rate. Therefore, weekly passes have been made available. There has also been established a Sunday pass which sells for 25 cents and permits the purchaser to take an unlimited number of rides on that day.

A Traction Conference Board, composed of both citizens and traction officials, has been organized to help run the property, thus tying in the public directly with the management.

The Coffin Award Plan is now in its third year. The first year it was won by the Chicago, North Shore and Milwaukee Railroad Company, and last year by the Northern Texas Traction Co., Forth Worth, Tex. Competition for the award this year was keen, thirteen companies being represented in the finals. They ranged from very small properties to some of the largest in the country, but the size of the property was of no consequence. The award is made by a special committee drawn from the American Electric Railway Association. The General Electric Company which in December, 1922, established the Charles A. Coffin Foundation, takes no part in the award except donating the medal and cash prize. The committee this year was composed of J. N. Shannahan, president of the Newport News & Hampton Ry., Gas & Electric Co.; F. R. Coates, president of the Toledo Edison Company; and J. H. McGraw, president of the McGraw-Hill Company.

LIBRARY SECTION

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Air Preheaters

Air Preheaters in the Power Plant.
Power Pl. Engng., Sept. 15, 1925; v. 29, pp. 940-943.
("Description of types now in general use and summary of results which may be expected from their use.")

Arc Welding

Current Values for Carbon Wire. Rusk, C. M.
Weld. Engr., Sept., 1925; v. 10, pp. 36, 47.
(Presents a chart for determining current values and densities for 0.18 carbon steel electrodes.)

Armature Windings

Direct Current Armature Windings for Multi-Polar Generators and Motors—Frogleg Windings. Powell, W. H. and Albrecht, G. M.
Iron & St. Engr., Sept., 1925; v. 2, pp. 345-354.

Cars, Gas-Electric

Gas-Electric Buses Used in Albany.
Elec. Rwy. Jour., Sept. 12, 1925; v. 66, pp. 391-393.
(Describes the Fageol-General Electric buses recently placed in service.)

Circuit Breakers

Selection and Maintenance of Oil Circuit Breakers. Burnham, George A.
Iron & St. Engr., Sept., 1925; v. 2, pp. 384-391.

Selection and Maintenance of Oil Circuit Breakers. Wohlgemuth, M. J. and Read, E. K.
Iron & St. Engr., Sept., 1925; v. 2, pp. 398-405.

Electric Cables

High-Voltage Cables. Beavis, E. A.
Elec. Rev., Sept. 18, 1925; v. 97, pp. 443-446.
(Mathematical treatment of dielectric loss and temperature rise under working conditions.)

Electric Drive—Air Compressors

Electric Drive of Air Compressors. Miller, L.
Met.-Vick. Gaz., July, 1925; v. 9, pp. 19-23.

Electric Drive—Steel Mills

Advantages of Adjustable-Speed Drives for Rolling Mills. Shirk, Wm. B.
Elec. Jour., Sept., 1925; v. 22, pp. 414-417.

Electric Furnaces

Electric Melting Furnaces. Seede, J. A.
Iron & St. Engr., Sept., 1925; v. 2, pp. 368-374.

Electric Met

Switchboard Meters for Power Plants. Housley, J. Elmer.
Power, Sept. 8, 1925; v. 62, pp. 362-364.
(General directions for their selection.)

Electric Motors, Induction

Effect of Unbalanced Secondary Conditions on the Operation of Large Induction Motors. Kenyon, A. F.
Elec. Jour., Sept., 1925; v. 22, pp. 435-437.

Electric Motors—Starting Devices

Design of Squirrel-Cage Motor Starters. Knowles, J. O.
Elec. Rev., Sept. 11, 1925; v. 97, pp. 404-406.
("Suggestions for alterations necessary to meet heavier load conditions.")

Electric Transformers

Polyphase Transformer Magnetizing-Current Wave-Forms. Kemp, P. and Young, H. P.
I. E. E. Jour., Sept., 1925; v. 63, pp. 877-895.
(Analyses the magnetizing currents taken by groups of transformers connected in various manners for operation on polyphase systems. Includes bibliography of 20 entries.)

Principles of Transformer Connections. Johnson, V. E.
Power Pl. Engng., Sept. 15, 1925; v. 29, pp. 956-958.
(Serial.)

Electric Transmission

Operating a Fully Interconnected System. Perry, Allen M.
Elec. Wld., Sept. 26, 1925; v. 86, pp. 657-662.
(Practices of the Consumers' Power Company of Michigan.)

Electrical Machinery—Temperature

Ventilation for Self-Cooled Transformers. Lennox, T. C.
Elec. Wld., Sept. 19, 1925; v. 86, pp. 569-570.

Elevators, Electric

Three-Speed Traction Elevator Direct-Current Controller. Armstrong, Charles A.
Power, Sept. 22, 1925; v. 62, pp. 438-441.
(Explains circuits and operation.)

Hydroelectric Plants

Operating Practice in Hydro-Electric Plants. Hawley, Charles B.
Engrs. & Engng., Sept., 1925; v. 42, pp. 235-245.
(A paper presented at the Third Annual Hydro-Electric Conference.)

Present Trends in Western Hydro-Electric Practice. Hutchinson, Ely C.
Elec. Wld., Sept. 26, 1925; v. 86, pp. 615-618.
(A discussion of water turbines, valves, governors, lubrication, etc.)

Illuminating Engineering

Year's Progress in Illumination, 1924-1925.
Illum. Engng. Soc. Trans., Sept., 1925; v. 20, pp. 679-800.
(The 1925 report of the Committee on Progress, I. E. S. Includes some 500 bibliographic footnotes and a list of recent books on illumination subjects.)

Insulating Oils

Purifying Circuit Breaker Oil. Clark, Lee Hinchman.
Elec. Wld., Sept. 19, 1925; v. 86, pp. 562-565.
(Describes a new process which combines centrifugal and chemical treatment.)

Isolated Plants

Justifiable Small Power Plants. Mallinson, A. B.
I.E.E. Jour., Sept., 1925; v. 63, pp. 896-915.
(Investigates the economics of the isolated plant.)

Measuring Instruments

The Rotoscope.
Engr., Sept. 11, 1925; v. 140, pp. 272-273.
(Illustrated description of the Ashdown Rotoscope, a device for visual inspection of rapidly rotating machine parts.)

Mercury Boilers

Status of Mercury Boilers.
Elec. Wld., Sept. 26, 1925; v. 86, pp. 607-608.
(Short account of a new installation in the Dutch Point station of the Hartford Electric Light Co.)

Nozzles

Supersaturated Steam in Turbine Nozzles.
Power, Sept. 22, 1925; v. 62, pp. 445-446.

Power Plants, Electric

Auxiliaries and Auxiliary Drives for Steam-Electric Generating Stations. Penniman, Jr., A. L. and Quarles, F. W.
Iron & St. Engr., Sept., 1925; v. 2, pp. 377-384.

Combustion Control at the Hudson Avenue Station. Holmes, W. C.
Elec. Wld., Sept. 26, 1925; v. 86, pp. 628-632.
(Illustrated account of equipment and methods used in the Hudson Avenue station of the Brooklyn Edison Co.)

Radio Engineering—Wave Propagation

On Recent Advances in Wireless Propagation Both in Theory and in Practice. Eve, A. S.
Franklin Inst. Jour., Sept. 1925; v. 200, pp. 327-333.

Regulators, Induction

Use of Induction Regulators in Feeder Circuits. Carr, Laurence H. A.
I. E. E. Jour., Sept., 1925; v. 63, pp. 864-876.
(Describes three types and explains their operation.)

Repair Shops, Electrical

What is a Reasonable Stock of Renewal Parts? Ahrens, A. G.
Elec. Jour., Sept., 1925; v. 22, pp. 432-434.
(Pertains to one of the management problems of electrical repair departments in steel mills and industrial plants.)

Silica, Fused

Mechanical, Thermal and Optical Properties of Fused Silica. Thomson, Elihu.
Franklin Inst. Jour., Sept., 1925; v. 200, pp. 313-325.

Standards, Electric

New Edition of A. I. E. E. Standards. Newbury, F. D.
Elec. Jour., Sept., 1925; v. 22, pp. 447-451.
(Presents a short history of the development of the old editions of the A.I.E.E. Standards. Explains the reasons for the revised form of the 1925 edition and summarizes the more important changes appearing therein.)

Statistics—Central Stations

Operating Performance of Steam Generating Stations. Alden, Vern E.
Elec. Wld., Sept. 26, 1925; v. 86, pp. 633-648.
(An analysis of the data presented in numerous tables and charts covering costs and thermal performances of 136 American coal-burning stations.)

Steam Plants

Analysis of Steam Station Design. Hirshfeld, C. F.
Elec. Wld., Sept. 26, 1925; v. 86, pp. 609-613.

Increased Economy Warrants Increased Investment. De Forest, C. W.
Elec. Wld., Sept. 26, 1925; v. 86, pp. 605-607.
(On the economical operation of steam generating plants.)

Steel—Electrometallurgy

Electric Heat Treating Furnace Applications. Hurme, E. A.
Iron & St. Engr., Sept., 1925; v. 2, pp. 357-368.

Heating of Ingots by Electricity. Butler, Ralph A.
Iron & St. Engr., Sept., 1925; v. 2, pp. 374-376.

Substations

Mine Substations Properly Equipped and Located Help Cut Down Power Costs. Borland, J. E.
Coal Age, Sept. 24, 1925; v. 28, pp. 421-425.
(Considers the selection and application of apparatus.)

Modern Transformer Station.
Elec. Wld., Sept. 19, 1925; v. 86, pp. 553-555.
(Illustrated account of a 110-kv. outdoor station built at Toronto by the Hydro-Electric Power Commission of Ontario.)

Switches and Switchgear

Steel Enclosed Switching Equipment for Steel Mill Service. Wohlgemuth, M. J.
Elec. Jour., Sept., 1925; v. 22, pp. 417-420.

Wattmeters—Testing

Testing Polyphase Watt-Hour Meters with Single-Phase Rotating Standard. Walsh, Willard F.
Power, Sept. 15, 1925; v. 62, pp. 399-402.

X-Rays

Steel Castings and X-Rays. St. John, Ancel.
Iron Age, Sept. 24, 1925; v. 116, pp. 802-804.
("How fluoroscopic examination may detect blow holes and slag—Possible substitution for radiography.")

NEW BOOKS

Aprovechamiento de las Energías Naturales. Juan Gelpí Blanco. 281 pp., 1924, Barcelona, Imprenta Altés.

(In this Spanish-language volume, the title of which might be translated to read "The Utilization of Natural Energy," the author presents a descriptive and mathematical treatment of modern engineering methods in the utilization of the sources of energy. Though he treats of power production in general, Sr. Blanco is particularly concerned with conditions in Spain. Briefly enumerated the subjects covered, as revealed by the titles of the nine chapters, are: Natural Sources of Energy; Importance of the Most Complete and Economical Utilization of Energy in Spain; Summary of Our Energy Supply; Modern Engineering Education; Results of Experiments with Modern Hydroelectric Plants; Heat Engines and Their Future; Electricity; Economic Aspects of Energy Supply; Necessity for Adopting Superpower Plans to Save Waste. The volume includes numerous graphs, drawings and tables of data.)

Automatic Telephony. An Outline. William Aitken. 143 pp., 1925, N. Y., D. Van Nostrand Co.

(Briefly outlines the principal apparatus and fundamental circuits used in the various systems of automatic telephony. Among the types discussed are the Western Electric rotary and panel type systems of machine switching, the straight Strowger and the Strowger director systems.)

Diesel and Oil Engineering Handbook. Ed. 3, enl. Julius Rosbloom. 794 pp., 1925, Los Angeles, Technical Pub. Co.

Electrical Precipitation. Sir Oliver Lodge. 40 pp., 1925, Lond., Oxford Univ. Press.

Elektrische Zugförderung; Handbuch für Theorie und Anwendung der Elektrischen Zugkraft auf Eisenbahnen. Ed. 2, rev. & enl. E. E. Seefehlner. 659 pp., 1924, Berlin, Julius Springer.

(Describes electric locomotives and rolling stock of all types from both the theoretical and the practical viewpoints, also line construction, substations, etc. A special section by H. H. Peter considers rack railways, cable railways and aerial tramways. The volume is exceptionally well illustrated and includes numerous bibliographies. One of the noteworthy features is a very complete table showing the principal design features of practically all types of electric locomotives for main line service thus far constructed throughout the world.)

Factory Organization and Administration. Ed. 4. Hugo Diemer. 298 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Light, Photometry and Illuminating Engineering. William E. Barrows. 412 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Resistance of Materials. Fred B. Seely. 442 pp., 1925, N. Y., John Wiley & Sons.

Rewinding Small Motors. Daniel H. Braymer and A. C. Roe. 247 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Sheet Metal Welding by the Oxy-Acetylene Process. T. C. Fetherston (Comp.) 259 pp., 1925, N. Y., Linde Air Products Co.

Sound, Light, Electricity and Magnetism. Ed. 2. William B. Anderson. 821 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Superheat Engineering Data. Ed. 6, rev., 208 pp., 1925, N. Y., Superheater Co.

("A handbook on the generation and use of superheated steam and related subjects." Although frankly a piece of trade literature, this volume contains much useful information in the form of tables and other data applying to boiler- and engine-room practice.)

Transactions of the First World Power Conference, London, June 30 to July 12, 1924. 5 vols., 7013 pp., 1925, Lond., Percy Lund, Humphries & Co., Ltd.

Paris International Conference on High-tension Lines

It is proposed, subject to there being a sufficient demand, to publish an English edition (in two volumes of about 1100 pages each) of the papers read at the International Conference on High-tension Lines held in Paris on June 16-25, 1925. The volumes will also contain a report of the discussions.

If the demand reaches 400 copies, the price will be four pounds for the two volumes, but in the event of 800 copies being subscribed for, the price will be two pounds ten shillings.

In order that an early decision may be arrived at as to whether to publish an English edition, those wishing to subscribe for copies are requested to inform without delay Monsieur Tribot Laspiere, Union des Syndicats de l'Electricité, 25 Boulevard Malesherbes, Paris, of the number of copies which they will require.

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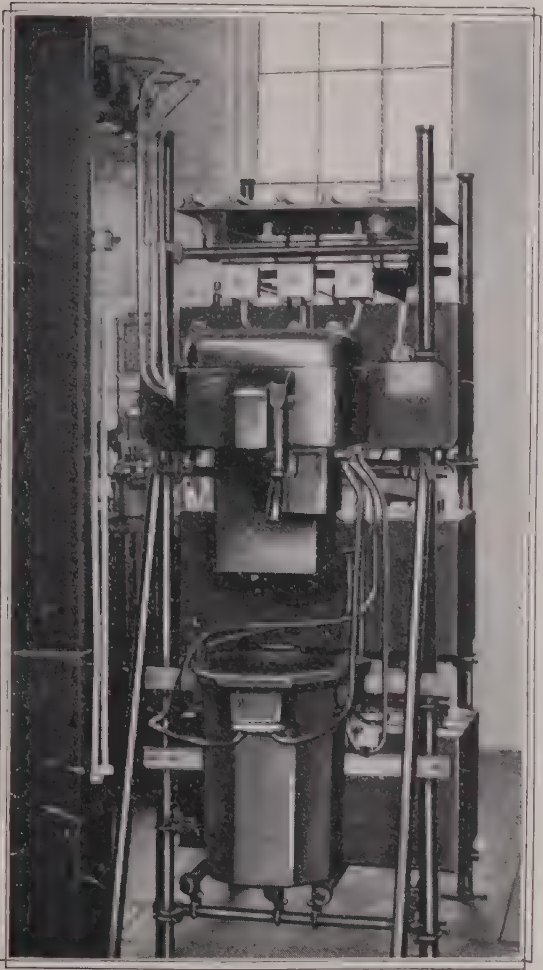

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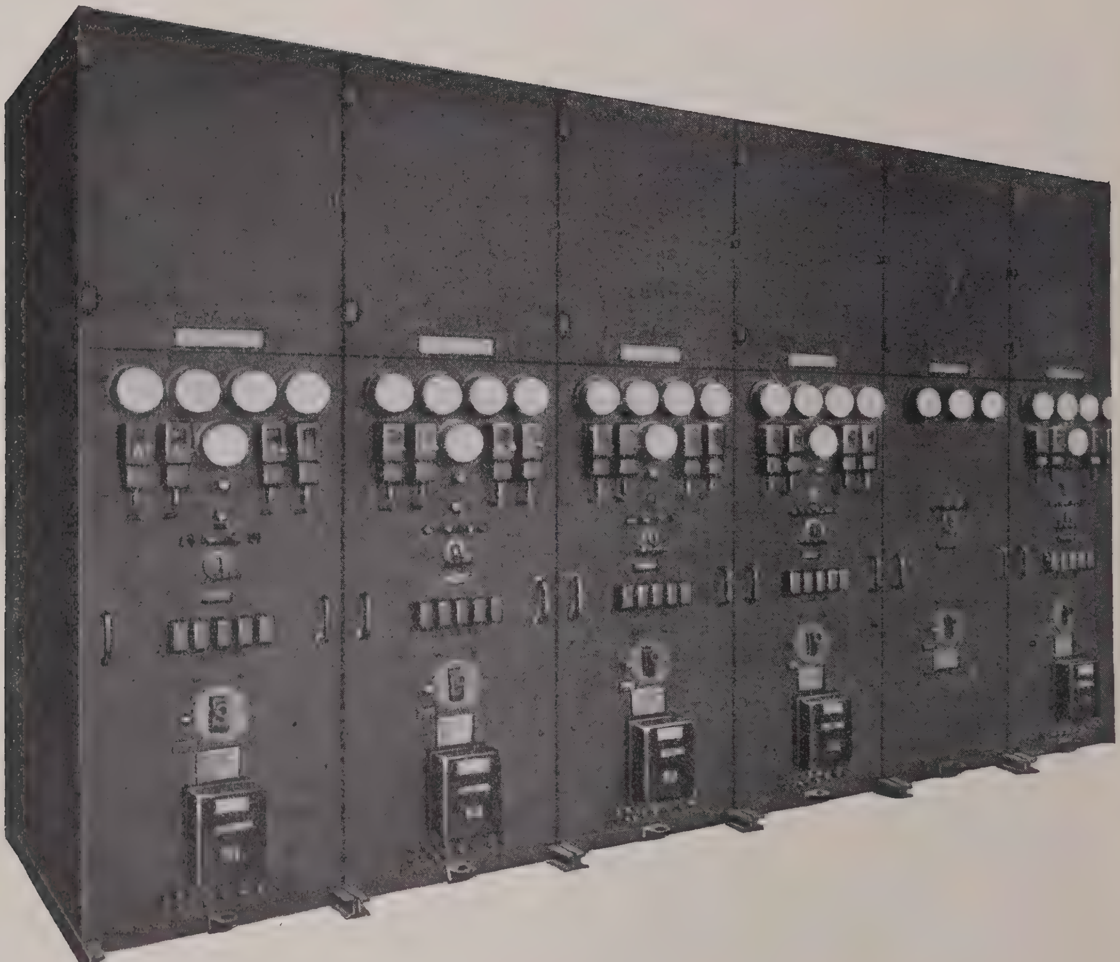

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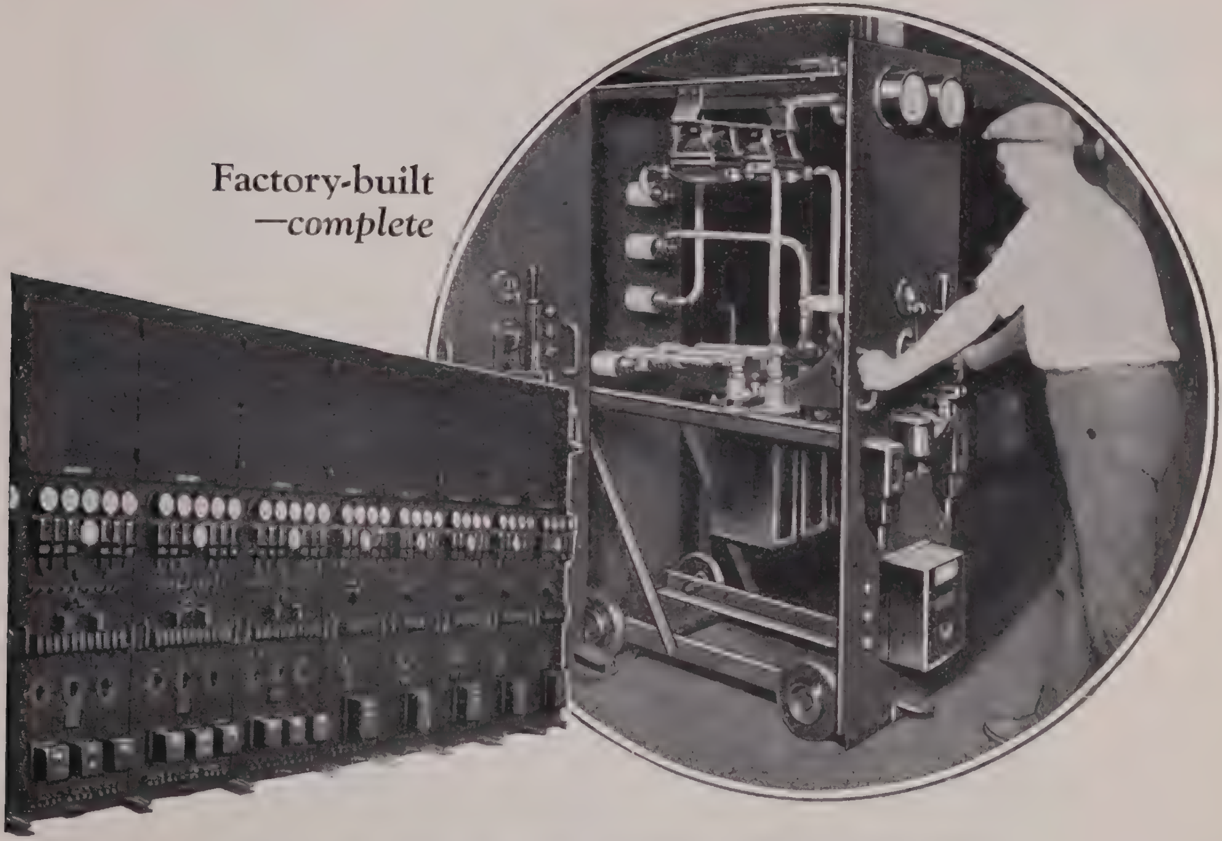

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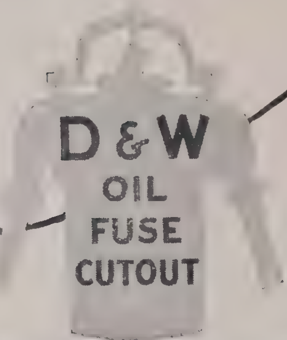

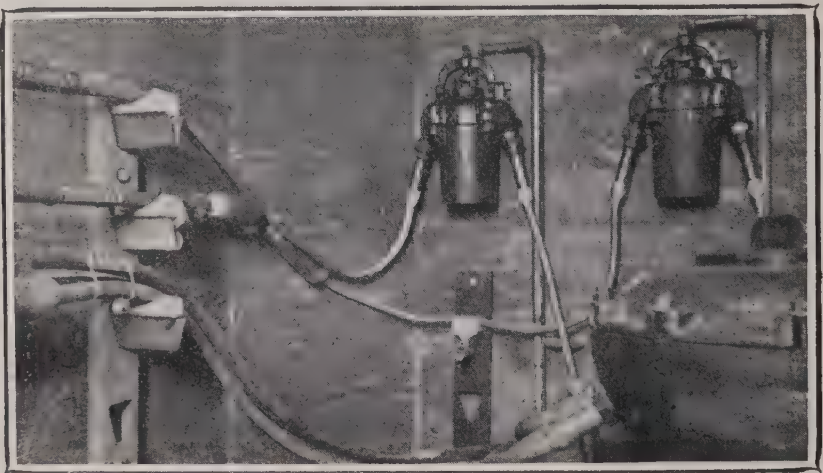

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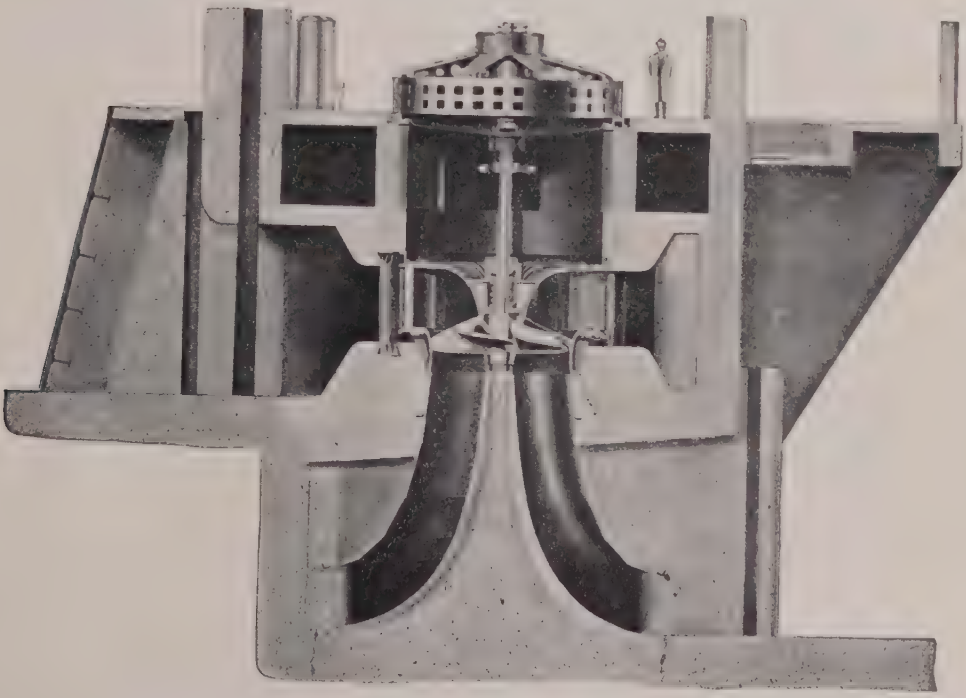

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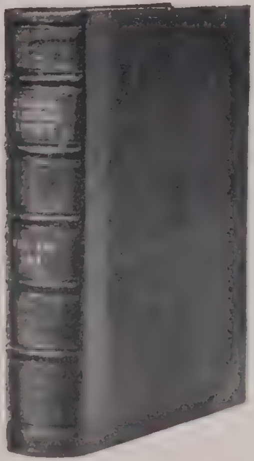

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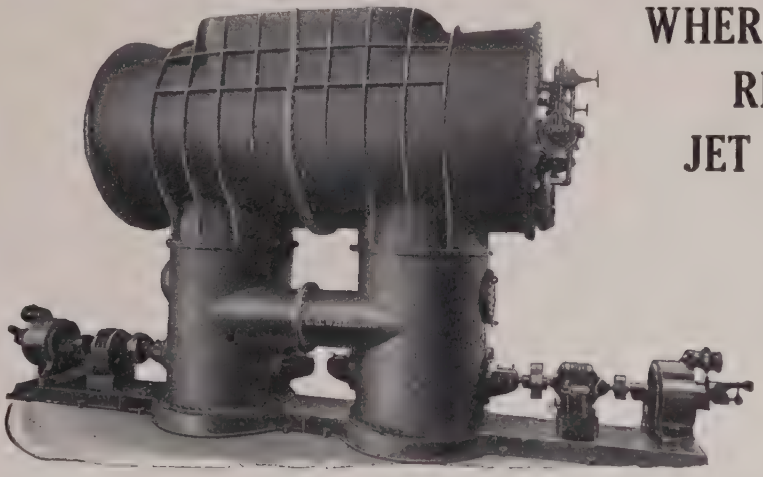

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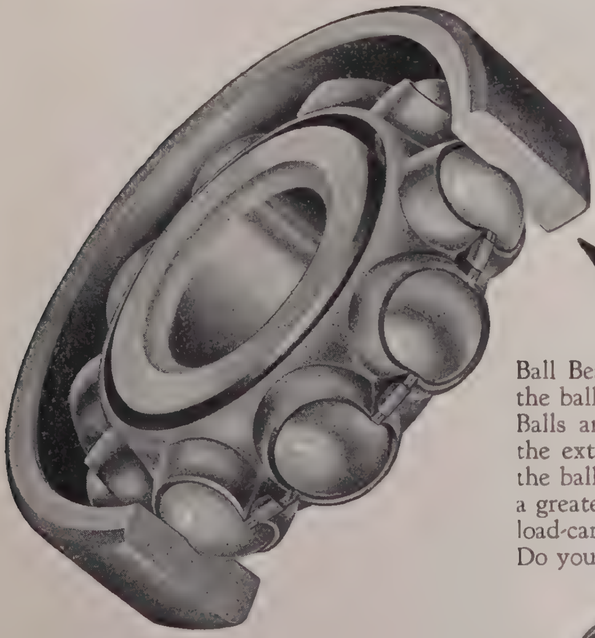

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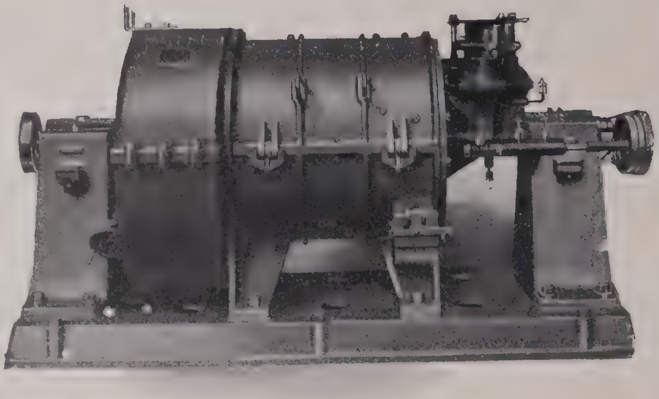

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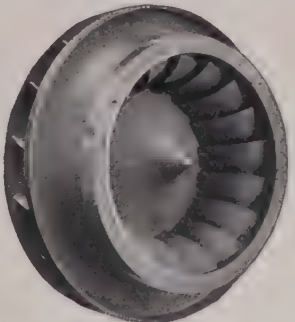

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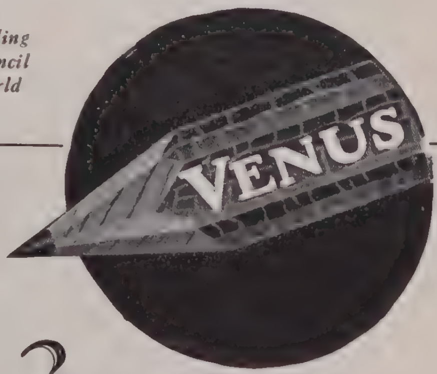

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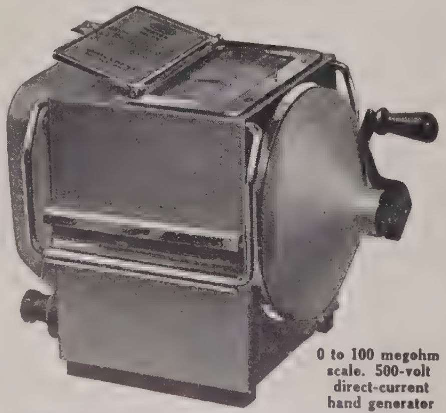
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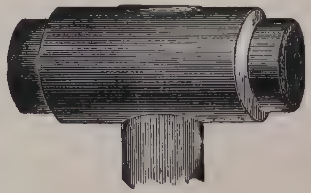

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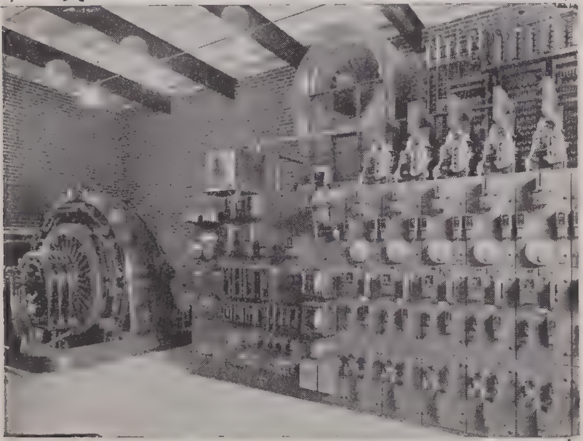

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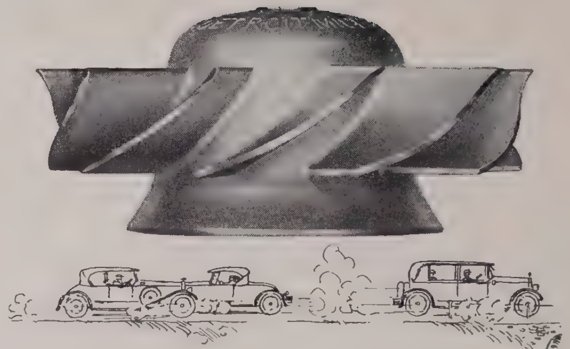

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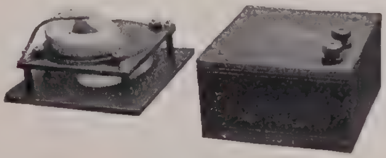

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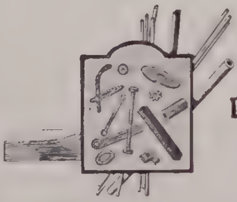

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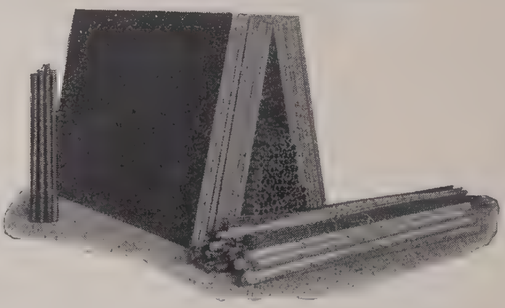

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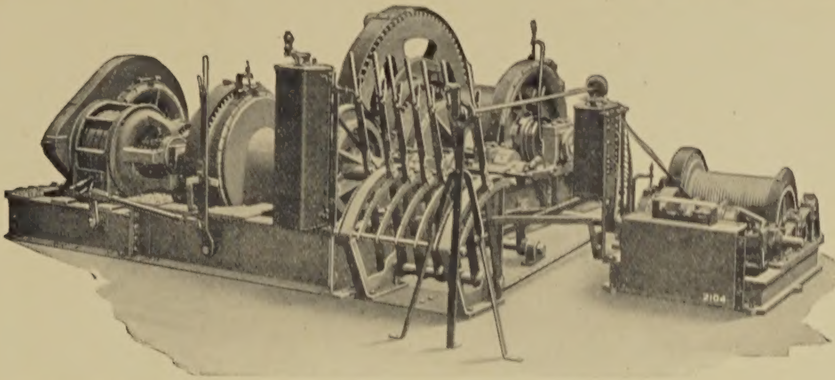

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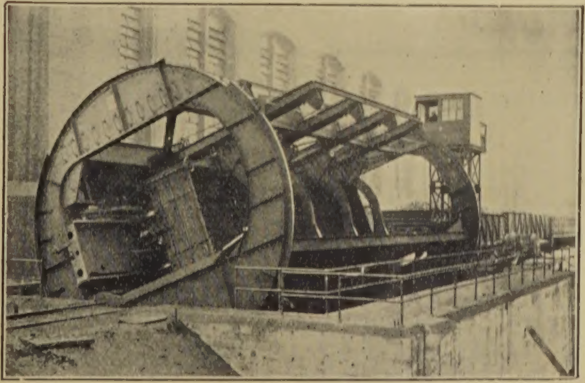

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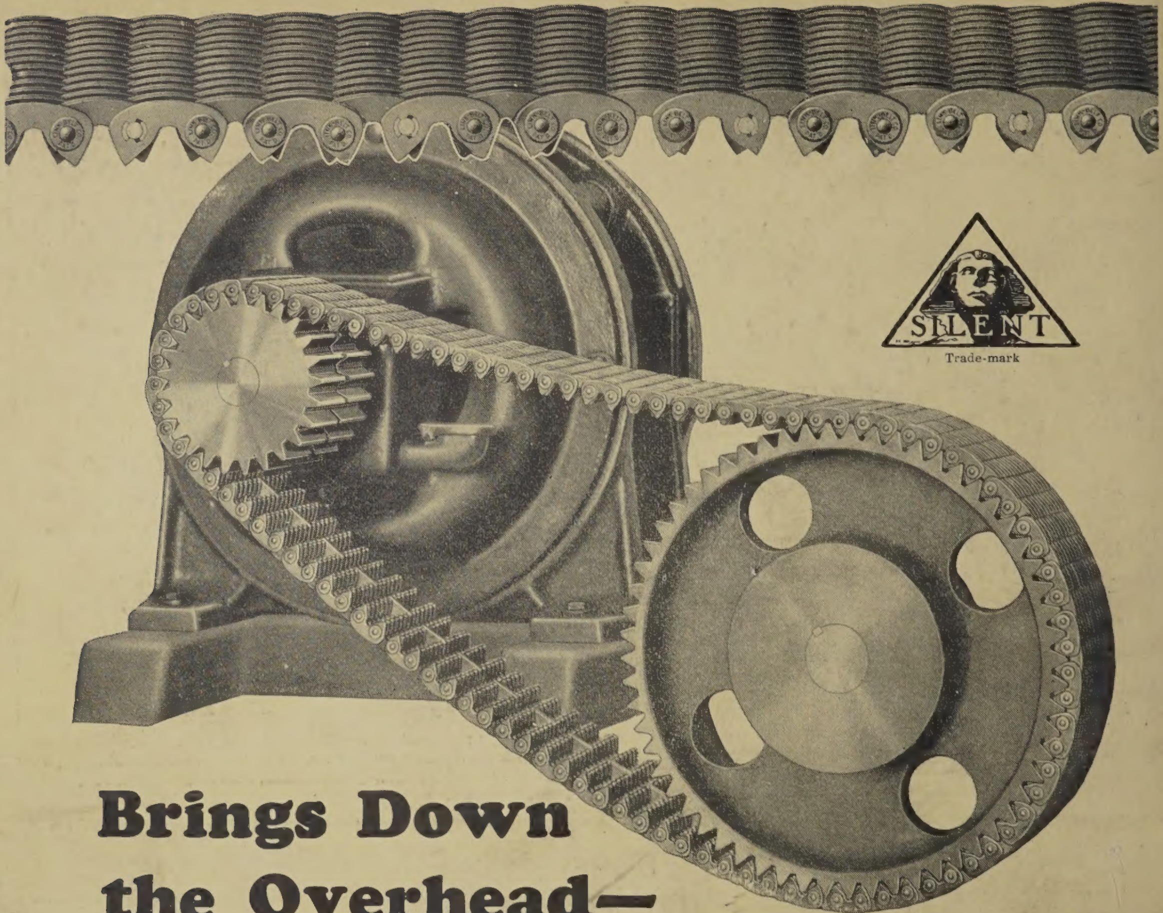

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